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Southern Ocean Indian Sector (SOIS) Working Group 1st Meeting Report

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Southern Ocean Indian Sector (SOIS) Working Group 1st Meeting Report

12-16 August 2017, Hayama, Kanagawa, Japan

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Executive Summary

Purpose of the meeting

The first meeting of the Southern Ocean Indian Sector (SOIS) Regional Working Group (RWG) was held in Hayama, Kanagawa, Japan on 12-16 August, 2017. Eighteen people attended the first meeting representing Japan, China, India, France and Australia.

The aims of the meeting were to:

i. identify the community of active researchers in the Indian Sector
ii. gain consensus on the key drivers in the region
iii. develop a picture of the status of multidisciplinary observations in the Indian Sector
iv. discuss key observational gaps, regional priorities, and challenges

Discussion covered a range of issues including research areas of common interest, current marine science activities in the Indian sector, key drivers in the region, the status of multidisciplinary observations, regional priorities and challenges.

Key points of the Meeting

The spatial scope of the area under interest was established to be from 20°E to 170°E and from the continent to 40°S, with a further area north to 30°S in order to include interactions with the Second International Indian Ocean Experiment (IIOE-2).

A system was proposed to partition the area into boxes (SOIS boxes) to enhance the focus of collaborations and co-ordination of multi-disciplinary observations and to be able to better specify observational needs for each box.

Each country presented a summary of their current activities within the Indian sector.

i. Japan undertakes routine marine science observations using both the icebreaker Shirase and TRV Umitaka-maru (along the 110°E transect). Long-term observations began in 1965/66 by NIPR.
ii. China have carried out multidisciplinary surveys in Prydz Bay since 1990 and they established an oceanography section along the front of the Amery Ice Shelf in 2003 (using their icebreaker Xuelong). They have undertaken a number of routine sampling across the ACC near to I9, I8 and SR3 GO-SHIP sections. They have also been doing routine fast ice work from Zhongshan Station.
iii. India have undertaken nine multi-disciplinary cruises since 2004, focussing on the region between 40°S and 69°S and 40°E and 80°E. They have developed a 5-10 year plan to continue working in the same region, with a strong focus on ocean-atmosphere interactions and phytoplankton dynamics.

i. French activities in the Indian sector are developed into two large marine regions: (i) the Permanent Open Oceanic Zone (POOZ), sampled annually from the RV Marion Dufresne, with a number of specific activities related to conservation issues in the region, and (ii) coastal monitoring from their station Dumont d'Urville occurs each summer focussing on Adelie penguins, seabirds, marine mammals, plankton and fish.
ii. Australia undertake repeat hydrographic transects (SR3, I9), the continuous plankton recorder (CPR since 1990), underway sampling from the icebreaker Aurora Australis, and monitoring of penguins and seals and flying birds. They have a number of operations relating to the Australian Integrated Marine Observing System including using seals to carry oceanographic devices (CTD), Argo floats, and the Southern Ocean Time Series moorings.

Meeting participants designed a method (heatmap) as a means of summarizing the complex mix of activities over many spatial and temporal scales. This will be filled in by each nation following the workshop.

Key drivers in the region were summarised to describe the ice and oceanographic features of each of the SOIS boxes.

i. Key physical features include horizontal advection due to eddies, the southward shift of the SACCf, freshening of Antarctic Bottom Water, poor representation of clouds in climate models, ice sheet dynamics, ice-ocean-atmosphere dynamics, polynyas and the timing of advance and retreat of sea ice.
ii. Important biogeochemical observations relate to how the Southern Ocean responds to anthropogenic climate forcing, how primary production will be modulated by nutrient supply, the role of iron inputs from the Kerguelen Plateau, changes to pCO2 on a seasonal basis, the fate of CO_2 and associated acidification, oxygen ventilation and nutrients to fuel production outside of the Southern Ocean.
iii. For lower trophic levels important features are the role of salps in forming alternative energy pathways in food webs, how the biology interacts with the environment, how climate modes (e.g. SAM) may influence biological variability (best assessed by the CPR at present), interactions between krill and its predators, the influence of sea ice melting on ice edge blooms, the strength of the fish-based food web and what is happening in the aphotic zone.
iv. For top trophic levels, climate is the principal driver; e.g. how does climate variability influence distribution and abundance of prey and the accessibility of breeding sites? There is an urgent need for long-term data sets for many top predators.
v. Benthic habitats require a detailed understanding of geomorphic features via bathymetric mapping. Describing species diversity in the habitats is needed in order to assess their potential responses to ecosystem variability,
vi. Key areas of human activities include the fishing industry and how stocks will respond to changing oceanographic conditions and the extent to which micro-plastics have entered the food chain.

i. The development of integrated model ‘toolboxes’ was highlighted as a way to fill gaps in observations and, in turn, inform observationalists about the data that are needed for the models.
ii. It was noted by the Meeting that a publication summarising the key SOIS drivers would be useful, along with clear definitions of the drivers. Summary attributes of each driver would be a useful first step.

Multidisciplinary observations will be important in developing a time-series of observations useful for the multidisciplinary studies envisaged to be supported by SOOS. Updates were given on current activities relevant to the development of multidisciplinary time series in SOOS:

i. Second International Indian Ocean Experiment, which has an overlapping interest in the northern area of the Southern Ocean Indian Sector,
ii. The development of spatial observations of top predators through the SOOS Capability Working Group on Censusing Antarctic Predators from Space (CAPS),
iii. Maintenance of sustained observations at mooring sites of physical, chemical and biological properties of phytoplankton and zooplankton related to the carbon cycle at the Southern Ocean Time Series (SOTS) site administered by IMOS, and
iv. Further development and refinement of Essential Ocean Variables (EOVs) within SOOS needed for multidisciplinary observing of Southern Ocean systems.

Next Steps

Consideration was given to the further development of the SOIS Regional Working Group in filling observational gaps, establishing regional priorities, and developing approaches to meet the challenges, including on

i. Refining the EOVs for the Indian Sector to achieve multidisciplinary observational time series,
ii. Establishing a catalogue of historical measurements in the region,
iii. Design strategies for the best temporal and spatial observations of the EOVs,
iv. Develop an inventory of existing and planned activities and programs, including availability of national platforms, and
v. Develop linkages amongst the regional research community.

Based on these points, a set of key objectives for the SOIS Regional Working Group for the next 5 years were agreed. Ideally, each country active in the region will be represented by experts ranging across the disciplines. These representatives would be asked to be points-of-contact in each country to help develop the SOIS RWG, encouraging scientists to participate in these activities. A minimum of 2 co-chairs from different countries is required.

Nineteen tasks for future work over the next 5 years were identified, including publications. These tasks would be undertaken by correspondence, as far as practicable. Task-oriented workshops were encouraged. The next meeting of the regional working group as a whole would be desirable within two years.

1. Introduction

1.1. Prof. Odate opened the first meeting of the Southern Ocean Observing System (SOOS) Southern Ocean Indian Sector (SOIS) Regional Working Group. The meeting was hosted by NIPR and TUMSAT at the Shonan Village, Hayama, Japan from 12th to 16th August 2017. The meeting was organised by Prof Odate and Dr. Moteki and co-chaired by Professors Odate and Koubbi and Dr. Constable.

1.2. The Working Group thanked the International Network Promotion Program of NIPR/ROIS, "SOOS RWG - Southern Ocean Indian Sector Regional Working Group (SOIS RWG) 2017 Meeting", for providing support to this meeting.

1.3. The participants of the meeting are listed below (see Table 1 and Figure 1).

1.4. Apologies were received from many other scientists wishing to participate in the working group, including from nations not represented at the meeting - New Zealand, Republic of South Africa, Republic of Korea, Russia and USA. It was noted that it would also be useful, in the future, to invite other nations which have been active in the past in the area, including the UK and Spain.

Aims

1.5. The aims of the meeting were to:

- Identify the community of active researchers in the Indian Sector of the Southern Ocean,
- Gain consensus on the key drivers in the region, particularly those of change
- Develop a picture of the status of multidisciplinary observations in the Indian Sector
- Discuss key observational gaps, regional priorities, and challenges

Agenda

1.6. The agenda and program are provided in Attachment A.

Written contributions

1.7. Written contributions and slides were provided in advance of the meeting by:

- Fishing industry - Martin Exel (Australia)
- Benthic habitats & Geomorphology - Alix Post (Australia)
- Indian Program - N. Anilkumar (India)
- IMOS Seal observations - Clive McMahon (Australia)
- Micro-plastics - Dana Bergstrom, John van den Hoff (Australia)
- Biogeochemistry and the S. Ocean Time Series - Tom Trull (Australia)
- Sea ice and sea-ice algae - Rob Massom, Klaus Meiners (Australia)
- Southern Ocean Clouds - Simon Alexander, Andrew Klekociuk (Australia)
- IMOS Australian Ocean Data Network Portal - Roger Proctor (Australia)

This Report

1.8. The report provides summaries of the presentations and the main outcomes and actions under each of the agenda items. Paragraphs are numbered for ease of reference. The report is not intended to be a complete synthesis of each section. The next steps towards developing a synthesis are considered under future work for each section. An overview of the future work is provided in Next Steps. Acronyms of general use in the report are listed in Attachment B. Tasks identified through the report are collated in Attachment D.

Table 1: Participants of the Southern Ocean Indian Sector 1st Meeting

Name	Country	Affiliation	Email
Tsuneo Odate	Japan	NIPR	odate@nipr.ac.jp
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Rajani Kanta Mishra	India	NCAOR	rajanimishra@ncaor.gov.in
Nick D'Adamo	IOC	IIOE-2	nick.dadamo@bom.gov.au

Figure 1: SOOS-SOIS-1 Working Group photo: (L-R) Masato Moteki, Rajani Kanta Mishra, Rowan Trebilco, N. Anil Kumar, Nick D'Adamo, Philippe Koubbi, Kerrie Swadling, Andrew Constable, Mark Hindell, Tsuneo Odate, Clive McMahon, Guoping Zhu, Takeshi Tamura, Ryosuke Makabe, Kohei Mizobata, Keishi Shimada, Jiuxin Shi, Kunio Takahashi.

2. The Indian Sector

2.1. The Working Group agreed that its spatial scope would be from 20°E to 170°E and from the continent to 40°S, with an extension further to the north to 32°S between South Africa and Australia in order to enable interactions with the Second International Indian Ocean Experiment (IIOE-2)(Figure 2). It recognised that these boundaries may change as the other regional working groups of SOOS become established, and potential shifts occur for better coordination of measurements. The reasons for the boundary are:

- It encompasses the CCAMLR Area 58, with extensions to the west, north and east to more fully include relevant fronts and topography of the Southern Ocean;
- The eastern boundary encompasses the Macquarie Ridge and seamounts to the south of the ridge. At present, it includes the Balleny Islands and waters to the west of the Ross Gyre;
- The western boundary includes Gunnerus Ridge and extends from South Africa to the Antarctic continent; and

2.2. The northern extension to 30°S provides overlap with IIOE-2, which will include an extension further to the west near South Africa in order to include the Agulhas retroflection between South Africa and 40°S.

2.3. A number of existing activities are being regularly undertaken in the sector including:

i. Existing WOCE/GO-SHIP transects (I6S, I8S, I9 and SR3);

ii. Other regularly occupied transects

a. India (50-60 degrees East),

b. Japan (110°E; 150°E, 60°S), and

c. France (January survey: Réunion-Crozet-Kerguelen- 56°S-Kerguelen-Saint Paul/Amsterdam - Réunion);

iv. Specific areas of activity by Japan, France, China, Australia

2.4. The Working Group agreed that partitioning the areas into boxes will provide easier reference and focus of collaborations and coordination of multi-disciplinary observations and multiple platforms, respectively. Such boxes will also be useful for reporting on the implementation of SOOS in this sector.

2.5. Figure 2 illustrates the proposed location of the boxes. Roughly corresponding to columns and rows; the numbering system is intended to provide easy reference to location within the Indian sector, i.e. 1.2 = column_1.row_2. The box boundaries are based on topography, sea-ice extent, currents and the main regions of primary production. Coordinates of the boxes are listed in Table 2.

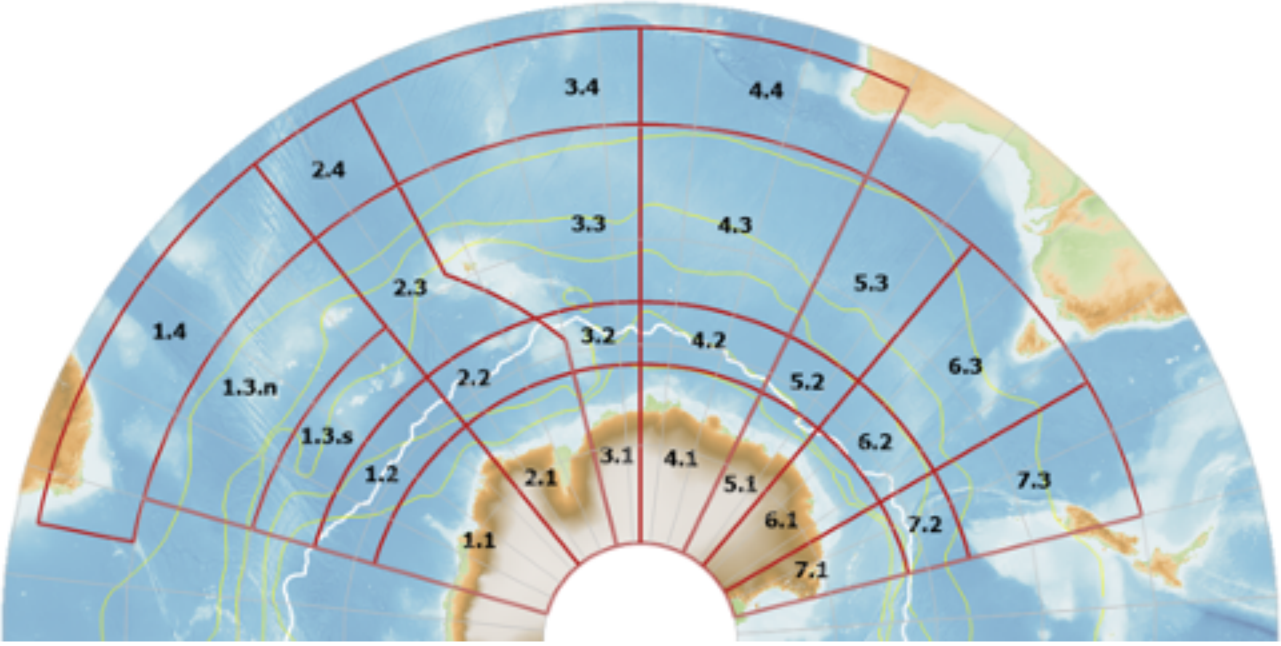

Figure 2: Map showing the spatial scope of the Southern Ocean Indian Sector Working Group and the partitioning of the sector into boxes for planning and reporting of observation activities (outer boundary is 30°S; vertical line at 94°E). The labels are shown for each box. Yellow lines show the fronts of Orsi et al. (1995) from north to south – Subtropical Front, Subantarctic Front, Polar Front, Southern Antarctic Circumpolar Current (ACC) Front, and the Southern Boundary of the ACC. The white line shows the maximum sea-ice extent in October 2016 (Cavalieri et al., 1996, updated yearly). Background is the bathymetry from ETOPO (Amante and Eakins, 2009). Grey graticule is shown at 10° intervals for latitude and longitude.

Table 2: Coordinates of the vertices of the boxes in the Indian Sector as illustrated in Figure 2.

Box	Coordinates
1.1	20 °E 62 °S; 55 °E 62 °S; 55 °E 80 °S; 20 °E 80 °S
1.2	20 °E 56 °S; 55 °E 56 °S; 55 °E 62 °S; 20 °E 62 °S
1.3.s	20 °E 50 °S; 55 °E 50 °S; 55 °E 56 °S; 20 °E 56 °S
1.3.n	20 °E 40 °S; 55 °E 40 °S; 55 °E 50 °S; 20 °E 50 °S
1.4	15 °E 32 °S; 55 °E 32 °S; 55 °E 40 °S; 15 °E 40 °S
2.1	55 °E 62 °S; 80 °E 62 °S; 80 °E 80 °S; 55 °E 80 °S
2.2	55 °E 56 °S; 76 °E 56 °S; 80 °E 58.8 °S; 80 °E 62 °S; 55 °E 62 °S
2.3	55 °E 40 °S; 66 °E 40 °S; 66 °E 49 °S; 76 °E 56 °S; 55 °E 56 °S
2.4	55 °E 32 °S; 66 °E 32 °S; 66 °E 40 °S; 55 °E 40 °S
3.1	80 °E 62 °S; 94 °E 62 °S; 94 °E 80 °S; 80 °E 80 °S
3.2	76 °E 56 °S; 94 °E 56 °S; 94 °E 62 °S; 80 °E 62 °S; 80 °E 58.8 °S
3.3	66 °E 40 °S; 94 °E 40 °S; 94 °E 56 °S; 76 °E 56 °S; 66 °E 49 °S
3.4	66 °E 32 °S; 94 °E 32 °S; 94 °E 40 °S; 66 °E 40 °S
4.1	94 °E 62 °S; 120 °E 62 °S; 120 °E 80 °S; 94 °E 80 °S
4.2	94 °E 56 °S; 120 °E 56 °S; 120 °E 62 °S; 94 °E 62 °S
4.3	94 °E 40 °S; 120 °E 40 °S; 120 °E 56 °S; 94 °E 56 °S
4.4	94 °E 32 °S; 120 °E 32 °S; 120 °E 40 °S; 94 °E 40 °S
5.1	120 °E 62 °S; 134 °E 62 °S; 134 °E 80 °S; 120 °E 80 °S
5.2	120 °E 56 °S; 134 °E 56 °S; 134 °E 62 °S; 120 °E 62 °S
5.3	120 °E 40 °S; 134 °E 40 °S; 134 °E 56 °S; 120 °E 56 °S
6.1	134 °E 62 °S; 154 °E 62 °S; 154 °E 80 °S; 134 °E 80 °S
6.2	134 °E 56 °S; 154 °E 56 °S; 154 °E 62 °S; 134 °E 62 °S
6.3	134 °E 40 °S; 154 °E 40 °S; 154 °E 56 °S; 134 °E 56 °S
7.1	154 °E 62 °S; 170 °E 62 °S; 170 °E 80 °S; 154 °E 80 °S
7.2	154 °E 56 °S; 170 °E 56 °S; 170 °E 62 °S; 154 °E 62 °S
7.3	154 °E 40 °S; 170 °E 40 °S; 170 °E 56 °S; 154 °E 56 °S

3. Current Marine Science Activities in the Indian Sector

3.1. This section provides abstracts on each of the presentations provided. The presentations were followed by a general discussion on how to summarise historical and current activities in the Indian Sector.

Japan

Tsuneo Odate: Current marine science activities in the Indian Sector: Japan

3.2. Routine Observations of Marine Science (Physical, Chemical and Biological Oceanography) have been conducted since 7th Japanese Antarctic Research Expedition (JARE) in 1965/66 austral summer. Physical and chemical oceanography was conducted by the Japan Coast Guard using R.V Fuji and R.V. Shirase until JARE-51. Since JARE-54, Physical and Chemical Oceanography has been conducted by NiPR and TUMSAT using R.V. Umitaka-maru. CTD casts are deployed to near the bottom. Using bottle water samples, nutrients and dissolved oxygen are determined following the WOCE protocol. The data from JARE-54 are available at https://scidbase.nipr.ac.jp/modules/metadata/index.php?content_id=271&ml_lang=en

3.3. Biological Oceanography has been conducted by NiPR until JARE-37. In JARE-38, it was renamed as Marine Ecosystem Monitoring, and is now conducted by NiPR using R.V. Shirase and R.V. Umitaka-maru. Current observations of this program are i) Surface observations (TS, Fluorescence, pCO2 (Shirase only)), ii) Station observations in ice-free water (CTD, nutrients, chlorophyll a, zooplankton), iii) Station observations in the sea-ice zone (CTD, nutrients, chlorophyll a, zooplankton), iv) Continuous Plankton Recorder, and v) Ocean Colour. These routine observations are conducted every year.

Masato Moteki: Ecosystem Research in the Southern Ocean by the Japanese Team

3.4. Since 2010/11, NIPR and TUMSAT have developed an MoU to undertake collaborative voyages on the training vessel Umitaka-maru . There are three target areas, off Syowa Station, Casey Station (along 110°E transect and its vicinity), and Dumont d'Urville Station (140°E transect). In the last five voyages, the area off Casey Station was the only targeted area. One of objectives is to understand the copepod-myctophid based food web in the Indian Ocean sector. Research on food web and geochemical cycles in the marginal ice zone during ice melting season (early December to January) has also be initiated, based on the hypothesis that the spawning and nursery grounds of myctophids (Electrona antarctica) are located vicinity of ice edge region.

3.5. Based on achievements of a series of projects on the spatial distribution of zooplankton and finfish, we have shifted to the next stage of research field, phytoplankton physiology, physical environment and productivity, sea-ice biota, early life history of Antarctic myctophid Electrona antarctica, food web and bio-geochemical cycles originating from sea ice. For these subjects, a project "Giant reservoirs of heat/water/material: Global environmental changes driven by Southern Ocean and Antarctic Ice Sheet" has begun with national funding support.

China

Jiuxin Shi: Current marine science activities in the Indian Sector - China

3.6. The oceanographic observations in Indian Sector of the Southern Ocean conducted by Chinese National Antarctic Research Expedition (CHINARE) have focused in the region of Prydz Bay. Since the 6th CHINARE in 1990, almost all CHINAREs that have engaged research vessels have carried out multidisciplinary surveys in several meridional sections (e.g. 70.5°E, 73°E, 75.5°E, 78°E) near Prydz Bay. CTD data spanning more than 20 years have been collected. An oceanographic section along the front of the Amery Ice Shelf (AIS) has been established since the 19th CHINARE in 2003, which has offered the opportunity to study ice shelf-ocean interactions.

3.7. In recent years, a zonal section along 67°15'S crossing the Prydz Channel between Fram Bank and Four Ladies Bank was added in order to investigate the shelf-basin exchange. CTD/LoweredADCP and turbulence profiler were deployed at these sections. Water samples were collected for chemical and biological analysis. Underway observations were conducted during the whole voyage of each cruise. After RV Xuelong was reconstructed in 2009, temperature, salinity and chemical variables (e.g., C02) of surface water were measured continuously and automatically with the support of a pumping system, while currents of the upper ocean were measured by ship-mounted ADCPs. XBT/XCTD probes and radiosondes were launched along the ship tracks across the ACC (nearly along GO-SHIP sections I8, I9 and SR3). ASPeCt sea-ice observations were conducted in ice covered regions since 2014. In 2012, 2014 and 2016, camps have been setup on the coastal fast ice near Zhongshan Station when RV Xuelong stopped there in early December. A CTD was driven by a programmed winch to accomplish a profile every 2 hours. ADCP was mounted in a hole to measure ocean currents under ice. Snow and ice thickness, radiation and meteorology were also observed at the camp. In the recent decade, moorings with sediment traps were deployed and recovered mainly in two regions, the mouth of the Prydz Bay for study of shelf-basin exchange and the east of the bay for collecting data and sediment samples.

Guoping Zhu: Biological and ecology studies of China in the Indian Sector of the Southern Ocean

3.8. In addition to the oceanographic observations and measurements, China has also conducted biological and ecological studies in the Indian Sector on the icebreaker "Xuelong". Over the past three decades, three main biological-related studies were conducted; microbiology (community composition, abundance, diversity and distribution of microbes, etc), phytoplankton (primary productivity, diversity and spatial-temporal distribution, etc.), and zooplankton (distribution and ecology of Euphausids (a priority focus), copepods, and salps, etc). These studies were highly focused in the Prydz Bay region. Additionally, fishing activities took place in the Indian Sector for the first time in early 2017 and data from this effort will be used in research on biology and ecology of krill and krill-fishing related species, particularly fish species. Although there has been a delay in accessing the data, due to the long operating time of the vessel in the Southern Ocean.

India

N. Anilkumar: Understanding the Southern Ocean Processes and Ecosystem Responses - Indian Expeditions highlights

3.9. The Ministry of Earth Sciences (MoES), Govt of India and National Centre for Polar and Ocean Research (NCPOR), Goa (an autonomous organisation under MoES) have initiated a long-term internationally coordinated program for planning and executing the research activities in the Indian Ocean sector of the Southern Ocean (Region between 40°S and 69°S and 40°E and 80°E). To date, nine multi-disciplinary and multi-institutional expeditions have been successfully implemented during the austral summer of 2004, 2006, 2009, 2010, 2011, 2012, 2013, 2015 and 2017 by NCPOR as the nodal agency, but with the involvement of a dozen leading institutions and Universities. The focus areas of research in the Southern Ocean realm include, at present, the following projects:

i. Hydrodynamics & Biogeochemistry of the Indian Ocean Sector of Southern Ocean,

ii. SOCCOM (Southern Ocean Carbon and Climate Observations and Modelling),

iii. High-resolution, long-term temperature measurements to quantify near-bottom internal wave mixing in the Prydz Bay,

iv. Biogeochemical response of Southern Ocean due to melting of Antarctic glaciers,

v. Quantitative and Qualitative Evaluation of Micro-plastics from the Southern Ocean,

vi. Oceanic volatiles and their impact on atmospheric halogens and cloud-forming aerosols in the Southern Ocean,

vii. Aerosol dynamics in the Indian Ocean sector of Southern Ocean (between 40°S and 65°S) in association with the spatial variability of marine atmospheric boundary layer,

viii. Paleoclimatology and paleoceanography of the Indian Sector of the Southern Ocean, and

ix. Quantitative Reconstruction of Past Southern Ocean and Southern Indian Ocean Climate and its Teleconnection with the Indian Monsoon.

Significant results have been achieved from the previous Southern Ocean expeditions, which have shed light on our understanding of the various physical and biogeochemical processes that are responsible for modulating global warming and climate variability. Based on these, more than 60 papers have been published in the national and international journals. Special issues in Current Science and Deep Sea Research II have also been published in November 2010 and August 2015 respectively.

3.10. During the next five-ten years, further studies are to be carried out on the following aspects:

i. air-sea interaction and aerosols studies to understand the radiative forcing and the associated effect on the climate;

ii. oceanic volatiles and their impact on atmospheric halogens and cloud forming aerosols;

iii. estimation of seasonal mixed layer depth;

i. spatio-temporal variability of Winter Water and its role in the mixed layer heat storage;

ii. meridional ocean heat transport from tropics to subtropics and polar regions and vice-versa.

These studies seek comprehensive understanding on variability and physical processes of the ocean and ice shelves in the coastal region of Antarctica, which may influence the rate of melting of the glacier, warming and freshening of bottom waters and increase sea-level rise. They will also focus on estimation of the vertical profile of phytoplankton biomass and carbon fixation rate by in situ and satellite remote sensing data. Studies will quantify carbon fixation rate by phytoplankton. Isotopic studies on thermocline species will be conducted to establish the nutrient supply from the Southern Ocean to tropical Indian Ocean. Tracking the movement of Antarctic melt-water using bio-optical techniques, and the deployment of moorings for time series observations for all seasons will also be conducted. Finally, numerical experiments using both the oceanic general circulation model and the coupled air-ocean–sea ice model will be conducted. The results of these investigations are expected to deepen our understanding of ocean-ice-atmosphere interactions and the multi-scale climate system.

R.K. Mishra: Biological processes in the Indian Ocean sector of the Southern Ocean

3.11. NCPOR has a focus on the role of biological processes in the Indian sector of Southern Ocean and global climate variability. Its main objectives are:

i. Understanding the biophysical processes and its impact on species specific and community of phytoplankton, primary production and microbial in the biogeochemical cycle,

ii. Study of sediment core from coastal Antarctica/Southern Ocean for understanding the role of phytoplankton cyst in biogeochemical cycle,

iii. Study to understand the spatial and diel vertical migration of zooplankton community structure and their role in the biogeochemical cycle,

iv. Study the variability of biochemical and isotopic composition of POM across different fronts,

v. Study the consequences of ocean acidification and its impact on Ocean biogeochemistry and marine organisms, and

vi. Retrieval and deployment of sediment trap mooring collecting the data including of salinity, temperature and oxygen at surface and subsurface in forthcoming expedition and further planning to add the sensor parameters such as, nutrient, turbidity and Chl a.

3.12. Results of these studies so far were presented. Future studies will include:

i. The predator-prey relationship (grazing), migration and frontal variability and their role in biogeochemical cycle;

ii. Sea ice impact on phytoplankton/zooplankton community in the biogeochemical cycle;

iii. Seasonal and inter-annual variability and long-term change in biological oceanography in response to any climate modes (El Nino, SAM, IOD, SIOD, Monsoon); and

iv. Study of mammal and birds and their sustainability in the Indian sector ecosystem

France

Philippe Koubbi et al.: French contributions to SOOS Indian sector

3.13. French activities in the Indian sector of the Southern Ocean are focused on two large marine regions (1) the Permanent Open Oceanic Zone with programs in the oceanic zone surrounding the French subantarctic islands, with the Kerguelen area being the most investigated; and (2) coastal East Antarctica. These activities are supported by various National, European and International programs and contribute data to several scientific databases.

3.14. Projects benefit from the logistic support of the French Polar Institute (IPEV). Their descriptions are on the following link http://www.institut-polaire.fr/ipev-en/support-for-science/supported-programs/

The RV Marion Dufresne operates North of 60°S in oceanic waters, whereas RV La Curieuse is working in the coastal zone of Kerguelen and RV L'Astrolabe in the Dumont D'Urville Sea. The former l'Astrolabe, has now been replaced by a new vessel that will also enable scientific work.

3.15. In all areas, investigations to assess the impacts of climate change are studied from the large scale (ACC, fronts, biogeographic provinces and ecoregions) to the mesoscale (island effects, eddies) and sub-mesoscale in the coastal zone and offshore (eddies filaments). The impact of climate change is considered to be very important in the subantarctic zone, with a shift to the South of the positions of the frontal regions (Constable et al., 2014; Reygondeau and Huettmann, 2014).

3.16. The scientific scope of the research programs are:

i. Studying the scales of oceanographic features (ACC, Frontal zones, role of the Kerguelen Plateau on circulation, eddies and island effects) by on-ship measurements, ARGO floats or through seals instrumented with bio-logging/telemetry platforms,

ii. Biogeochemistry and monitoring of oceanic CO_2, acidification and HNLC / iron enrichment,

iii. Spatio-temporal trends of biodiversity in the epi- and mesopelagic realms and important seabird and marine mammal areas,

iv. Conservation issues related to i) fisheries, ii) Vulnerable Marine Ecosystems, iii) Marine Protected Areas in the Southern French Territories (Kerguelen, Crozet, Saint Paul and Amsterdam) and in East Antarctica (Australia-EU proposal to CCAMLR).

Life science projects are grouped in the "Zone Atelier Antarctique" of CNRS which is a Long-Term Ecological Research program.

3.17. In the Permanent Open Ocean Zone, a group of programs are run annually during austral summer on RV Marion Dufresne between the subtropical and the Antarctic waters. It combines programs on seismicity (OHASISBIO), oceanography and biogeochemistry (OISO), ecology of plankton and mesopelagic fish (OISO, THEMISTO, MDCPR, REPCCOAI, MESOPP, MOBYDICK) and ecology of top predators (THEMISTO, OHASISBIO). In addition, Biogeochemical Argo Floats (SOCLIM) and SOCCOM floats are deployed in the area. Monitoring and bio-logging of seabirds and seals is the other long term and regular set of data that are collected (ORNITHOECO, MEOP, MEMO). Other programs are held regularly to study oceanographic (TRACK), biogeochemical (ACE, SWINGS, GEOTRACES), and ecological features (Fisheries and VMEs). In addition to these main areas of investigations around the French subantarctic islands, continuous oceanographic measurements are taken from Hobart to Dumont d'Urville (MINERVE and SURVOSTRAL).

3.18. A number of studies are undertaken in East Antarctica. In 2008, Australia, Japan and France worked together in the sea-ice zone in the d'Urville Sea for the Collaborative East Antarctic Marine Census, a Census of Antarctic Marine Life project. In addition, over the continental shelf, yearly surveys for studying oceanography and pelagic species were conducted from 2003 to 2011. From Dumont d'Urville French base, projects are carried out on the nearshore ecology of plankton and fish (ICO²TAKs) or benthos (REVOLTA) and on the long-term monitoring of seabirds and marine mammals using, among others, bio-logging (ORNITHOECO, AMMER and ASSET). Major changes in the area (calving of the Mertz Glacial Tongue, changes in the sea-ice regime, Adelie chick's massive mortality events) justify the joint proposition by Australia and EU to create an MPA as a scientific reference area with long-term monitoring.

Australia

Andrew Constable: Australian Research in the Southern Ocean Indian Sector

3.19. Australia's Southern Ocean research activities are organised through the Australian Antarctic Science program within the guidelines of the Australian Antarctic Science Strategic Plan 2011/12 to 2020/21 (http://www.antarctica.gov.au/science/australian-antarctic-science-strategic-plan-201112-202021). More recently, the Australian Government released its Australian Antarctic Strategy and 20 Year Action Plan, parts of which relate to marine science (http://www.antarctica.gov.au/__data/assets/pdf_file/0008/180827/20YearStrategy_final.pdf). An important component of this strategy is for the Australian Antarctic Division (AAD) to build and operate a new icebreaker to replace the RV Aurora Australis in 2020. Additional Australian efforts include the Integrated Marine Observing System (IMOS, considered below), the Antarctic Climate and Ecosystems Cooperative Research Centre and the Antarctic Gateway Partnership: a special research initiative of the Australia Research Council. Southern Ocean operations and many science programs are coordinated through the AAD, CSIRO and IMOS. Other government agencies are directly engaged with research, including the Bureau of Meteorology and Geoscience Australia. Many universities participate in Southern Ocean research, including University of Tasmania (Institute for Marine and Antarctic Studies), Macquarie University and the University of New South Wales. Australia has a number of long-standing observation activities including repeat hydrographic transects (SR3, I9), continuous plankton recorder (CPR), underway sampling from the RV Aurora Australis and L'Astrolabe, monitoring of penguins and seals from the continental and subantarctic stations. It has also undertaken some large-scale surveys to underpin longer term studies, including BROKE, BROKE West, the Kerguelen Axis and HEOBI.

Clive McMahon, Mark Hindell, Rob Harcourt: IMOS, monitoring & animal oceanographers

3.20. IMOS provides a national, multi-institutional capability to undertake sustained, systematic observing of the marine environment, from the open ocean onto the continental shelf and into the near-coastal regions around Australia. All of the observations collected by IMOS produce data streams in near real-time that are discoverable and freely accessible and usable through the Australian Ocean Data Network (AODN). These observations, across ocean-basins and regional scales, cover physical, chemical and biological variables. The operational component of IMOS is coordinated through eight different institutions within the National Innovation System, and these facilities are funded to deploy equipment and deliver data streams for use by the entire Australian marine and climate science community and its international collaborators. The scientific guidance for the operations is overseen by science planning through the IMOS regional "Nodes" with input from the Australian marine and climate science community, government, industry and invested stakeholders.

3.21. Weddell and elephant seals carrying satellite-linked Conductivity-Temperature-Depth relay loggers provide essential high-resolution ocean observations south of 60° South. These unique observations (14-year continuous time series in the Indian Sector of the Southern Ocean) form a major part of Australia's sustained contribution of ocean observations to the Global Ocean Observing System (GOOS) and SOOS. Along with the Argo observations, the seal derived-observations extend the IMOS capability into regions of national and international significance by providing essential data to identify regions of Dense Shelf Water formation and ocean/ice shelf interactions. Together, Argo and Satellite Animal Tracking (SAT) provide within IMOS the most comprehensive overview of ocean state across space and time and are highly complementary. These data, and their uptake, specifically address the Blue Water & Climate Node Science and Implementation Plan by providing "essential observations for improving understanding of the ocean's role in climate and for tracking the evolution of climate change on decadal time-scales". Argo provides high precision observations that are used in the quality control for the SAT-derived observations, while the seal-derived observations provide greater spatio-temporal coverage across areas that are essentially impossible to monitor reliably by conventional means e.g., ships, Argo and gliders, during the autumn to spring period when the seasonal sea ice zone expands to cover an area nearly three times that of Australia. Of particular interest are the continental slope and shelf regions around Antarctica, many of which are rarely sampled, other than by seals. Importantly, the seal-derived observations are widely used by the international community and assimilated into several international models e.g., Mercator and the Southern Ocean State Estimate (SOSE).

Discussion & Future Work

3.22. Workshop participants designed a 'heat map' for presenting data collected by each nation in different parts of the Indian Sector (Figure 3). For each box (Figure 2), we sought to summarise the types of physical, chemical and biological measurements that have been taken, what sampling design was used, and for how many years the data were collected (approximately). It was recognised that the table would require input from experts not at the meeting, including from countries not represented. Thus, this summary would be developed after the meeting by each nation. A compiled summary for the SOIS would be derived from these submissions.

Task 1.Experts from each participating nation to summarise measurements taken by their nation in the Indian Sector using the heatmap approach in Figure 3.

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4. Consideration of Key Drivers in the Region

4.1. The Indian Sector is characterised by the zonal frontal systems and the main topographic features, including the continental shelf, the Kerguelen Axis (Kerguelen Plateau, Princess Elizabeth Trough, Prydz Bay), the Macquarie Axis (Campbell Plateau, Macquarie Ridge, seamounts and Balleny Islands), the western subantarctic island chain (Crozet, Prince Edward, Marion Islands and Del-Cano Rise), and the chain of seamounts associated with Ob and Lena Banks. It is bounded to the eastern remnants of the Weddell Gyre (in the west) and by the western margin of the Ross Gyre (in the east). Ice plays a major role in the southern part of the sector, including ice shelves, areas of fast ice and perennial pack ice, and the annual advance and retreat of the seasonal sea ice zone. A summary of geophysical attributes of each SOIS Box is shown in Table 3.

4.2. Some special issues and synthesis papers of relevance to the region include

i. Bathymetry and geomorphology (Beaman and O'Brien, 2011; Beaman et al., 2011; O'Brien et al., 2009),

ii. Environmental setting (Post et al., 2014),

iii. Nutrients, biogeochemistry and the carbon cycle (Blain et al., 2014; Blain et al., 2008; Bowie et al., 2011; Trull et al., 2001)

iv. Sea ice systems (Fraser et al., 2012; Massom et al., 2013; Meiners et al., 2016; Worby et al., 2011)

v. Biodiversity (De Broyer and Koubbi, 2014; Schiaparelli and Hopcroft, 2011)

vi. Pelagic Ecosystems (Moteki et al., 2017; Nicol and Meiners, 2010; Nicol et al., 2000; Nicol and Raymond, 2012; Welsford and Duhamel, 2011)

vii. Benthos (Hosie et al., 2011; Jansen et al., 2018)

Figure 3: Screen shot of an Excel table illustrating a summary of the approximate number of years that physical, chemical and biological measurements have been taken in each box of the Southern Ocean Indian Sector (from Figure 2). For some measurements, the type of samples used to take the measurements are shown. This type of summary is to be developed for each nation, as well as a summary across all nations. Colours correspond to a colour ramp from 1 (yellow) to 25 (green). SSH = Sea Surface Height; CTD = Conductivity, Temperature, Depth; DO = Dissolved Oxygen; pCO2 = partial pressure of CO2; Sh = Ship casts; Se = Seal tracking; Fl = Floats; UW = underway seawater sampling; CPR = continuous plankton recorder.

Sections / Transects	Bathy-metry	Currents	SSH	CTD				DO	pCO2	pH	Nutrients		Trace elements	Passive sound	Sea ice thick	Sea ice conc	Mic-robes	Chloro-phyll	Pig-ments	Phytoplankton		Zooplankton				Acoustics	Fish			Birds & Marine Mammals			Ben-thos
				Sh	Se	Fl	UW	Sh	Sh	Sh	Sh	UW								Sh	UW	Nets	CPR	UW	Video profiler		Larvae	Pelagic	Dem-ersal	Breed	At-sea	Track	
GO-SHIP I6																																	
GO-SHIP I8																																	
GO-SHIP I9																																	
GO-SHIP SR3																																	
110°E																																	
150°E																																	
Boxes																																	
1.1			25												10	25						10								25	0	10	
1.2			25	10												25						5	5										
1.3s			25																				5										
1.3n			25																				5										
1.4			25																				5										
2.1			25													25																	
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4.1			25					10								25				2	2	25	20	5		10	5				2		
4.2			25					10								25				2		25	20	5		10	5				2		
4.3			25					10														25	20	5		10	2						
4.4			25					10														25	20	5		10							
5.1			25													25																	
5.2			25				10									25		10					10										
5.3			25																														
6.1			25													25						25	20										
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6.3			25																			25	20										
7.1			25													25																	
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7.3			25																														

Table 3: Summary attributes of each of the SOIS Boxes illustrated in Figure 2. (Possible names for the areas are underlined).

Box	Topography	Oceanography	Ice
1.1	Gunnerus Ridge, Continental Shelf	SACCF-Coast	Shelves, Fast ice, SIZ
1.2	Abyss	PF-SB	SIZ
1.3.s	Ob and Lena Banks	SAF-SA	NA
1.3.n	Western subantarctic islands, Del-Cano Rise	STF-PF	NA
1.4	African continental shelf, Madagascar Plateau and ridge; Southwest Indian Ridge		
2.1	Continental Shelf, Prydz Bay	SACCF-Coast; Prydz Gyre	Shelves, Fast ice, SIZ
2.2	Western margin Kerguelen Axis, Elan and BANZARE Banks	SACCF	SIZ
2.3	Western margin Kerguelen Axis	STF-SACCF	NA
2.4	Abyss	Agulhas	NA
3.1	Continental Shelf, Princess Elizabeth Trough	SB-coast	Shelves, Fast ice, SIZ
3.2	Southern Kerguelen Plateau	SACCF-SB	SIZ
3.3	Northern Kerguelen Plateau	STF-SACCF	NA
3.4	Amsterdam Island, Southeast Indian Ridge		NA
4.1	Continental Shelf, Bruce Rise	SB-Coast	Shelves, Fast ice, SIZ
4.2	Australian Antarctic Basin	SACCF-SB	SIZ
4.3	Southeast Indian Ridge	STF-SACCF	NA
4.4	Diamentina Escarpment, Australian continental shelf	Leeuwin Current, STF	NA
5.1	Continental Shelf, [Wilkes]	SACCF-coast	Shelves, Fast ice, SIZ
5.2	Australian Antarctic Basin	PF-SACCF	SIZ
5.3	Southeast Indian Ridge	STF-PF	NA
6.1	Continental Shelf	SACCF-coast, D'Urville Sea	Shelves, Fast ice, SIZ
6.2	Australian Antarctic Basin	PF-SACCF	SIZ
6.3	Tasmania, South Tasman Rise	STF-PF	NA
7.1	Balleny Islands, Continental Shelf	SACCF-Coast	Shelves, Fast ice, SIZ
7.2	Pacific Antarctic Ridge, Macquarie Ridge	SAF-SACCF	SIZ
7.3	New Zealand, Campbell Plateau, Macquarie Ridge	STF-SAF	NA

Ice-Ocean-atmosphere

Kohei Mizobata:

4.3. Mesoscale features have been identified in the Indian Sector of the Southern Ocean using satellite altimetry and ocean colour sensors. The complex relationship between eddies and high Chl a implies that unknown mechanisms governing primary production still exist, likely related to horizontal advection due to eddies. Also, the southward shift of the Southern Antarctic Circumpolar Current front, which is driven by changing Atmospheric forcing, will induce the eddy activity in the shelf-slope area resulting in carbon export to offshore. The variability of the carbon uptake in the Southern Ocean through the variability of the eddy field is strongly linked to SOOS themes 4 & 6 and should are a priority to be addressed.

Keishi Shimada: Increasing impact of Antarctic Bottom Water freshening on Sea Level Rise in the Australian-Antarctic Basin

4.4. Significant freshening of Antarctic Bottom Water (AABW) in the Australian-Antarctic Basin is reported in previous studies (Aoki et al., 2005; Rintoul, 2007). Its induced halosteric Sea Level Rise (SLR) is, however, regarded as negligible against thermosteric SLR. In this study, recent state is assessed using Conductivity-Temperature-Depth (CTD) data obtained after 2012 by Umitaka-Maru. It is clear that significant freshening of AABW has continued after 2012 with it vertical extent increasing. While inter-annual variability dominate temperature and salinity change in the shallower layers above 2000 m, warming and freshening in deep layers below 2000 m monotonically increase with time. Thence, multi-decadal deep halosteric (5.2±2.5 mm/decade) and thermosteric SLR (7.6 ±3.9 mm/decade) explain 22.5 and 33.2 % of total steric SLR (23.0±7.1 mm/decade), respectively. It is thus concluded that, at least in the continental rise to slope region, where newly-ventilated AABW is located, the impact of AABW freshening against SLR is statistically significant and is no longer negligible.

Simon Alexander, Andrew Klekociuk: Southern Ocean clouds

4.5. Southern Ocean clouds are poorly represented in climate models and reanalyses. In the models, too much short-wave radiation is absorbed, inducing warm sea surface temperature biases. A major contribution is from a lack of clouds in the cold sector of cyclones; purer air mass than in the NH, and a higher frequency of multi-layer mixed-phase clouds (super-cooled liquid water clouds).

4.6. The Antarctic Cloud and Radiation Experiment (ACRE) is part of the Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study (SOCRATES). This program is being run over 2016-2019.

- Surface-based observations include:
  - Cape Grim depolarisation lidar Jul 2013 – Feb 2014 - depolarisation allows characterisation of cloud phase
  - CAPRICORN cruise, mid-Mar to mid-Apr 2016 - between Tasmania and ~53˚S using the depolarisation lidar plus cloud radar and a microwave radiometer
  - Macquarie Island, Mar 2016 – Mar 2018 - depolarisation lidar, cloud radar, radiometers

- Other observations will include:
  - RSV Aurora Australis Oct 2016 to Feb 2017 using radiometers, cloud camera, ceilometer.
  - Ross Sea cruise by The World, Jan 2017 using distrometer, cloud camera and radiometers for P-E measurements.
  - RSV Aurora Australis 2017/18 Summer with extensive instrumentation
  - Davis 2019-2020 Winters using cloud and precipitation instruments.

4.7. At present, this work is producing a multi-instrument data set for Macquarie Island (and eventually the SO transects), along with basic statistics on cloud and aerosol properties, including cloud and aerosol 'fingerprinting', cloud bottom and top heights, and occurrence statistics for cloud types.

Takeshi Tamura: Japanese recent activities and future plan - Direct observations of coastal polynyas and glacier-ocean interaction in the East Antarctica

4.8. Under the framework of the Japanese Antarctic Research Expedition (JARE), the National Institute of Polar Research (NIPR) and Institute of Low Temperature Science (ILTS - Hokkaido University), have implemented a research project called ROBOTICA (Research of Ocean-ice BOundary InTeraction and Change around Antarctica). This is the core program of the prioritised studies of the 9th six-year plan (2016-2022) of the JARE for interactive processes mechanisms involving the ocean, sea ice and ice sheet/glaciers. The major target areas are the regions off the Totten Glacier and the Cape Darnley Polynya, and Lützow-Holm Bay/the Cosmonaut Sea. By fully utilising the capability of the icebreaker Shirase and developing/implementing automated multi-disciplinary research techniques that include remotely-operated vehicles, we are exploring fields not observed to date. Through utilisation and analysis of the satellite observation and numerical modelling, we aim at understanding both phenomena and underlying dynamics. Our science questions are related to all of the six themes of SOOS science priorities. We will promote participation of early career researchers in the field campaign, and seek opportunities for international collaborations. Through these activities, we will contribute to Antarctic science.

Rob Massom, Klaus Meiners: Sea ice

4.9. The sea ice cover of the Indian Ocean Sector is narrow yet complex, comprising a number of large-scale elements that are largely seasonal (though in certain areas, perennial) (Massom and Stammerjohn, 2010). These are: coastal landfast ice; a broader inner pack ice zone; and an outer pack ice or seasonal sea ice zone (SIZ) that is strongly affected by ocean waves. In the coastal zone, where sea ice characteristics are strongly affected by interaction with the ice-sheet margin and icebergs, recurrent polynyas play a crucial role as sea ice "factories" in the freezing season and areas of enhanced melt and biological activity in spring-summer (Barber and Massom, 2007).

While overall sea ice extent has displayed a slight increasing trend in the Indian Sector over the satellite period since 1979 (Comiso et al., 2016), there is considerable spatial complexity in observed patterns of change and variability in the timings of annual sea ice advance and retreat and thus duration across the region

(Massom et al., 2013). Broadly speaking, sea ice duration has been lengthening in the eastern part of the sector while decreasing around BANZARE Bank and in the western margins of Prydz Bay.

Important attributes of the sea-ice zone include not only the extent and seasonality of the ice but also its thickness, concentration and type (age), along with the thickness of snow on its surface and the drift of the ice as it affects its degree of deformation (a key factor affecting sea ice suitability as habitat for juvenile Antarctic krill). Taken together, these characteristics affect key air-sea-ice interaction processes as well as the biology/ecology of the Indian Ocean sea-ice zone (Massom and Stammerjohn, 2010), including the key role of the SIZ in driving phytoplankton blooms. Regarding the measurement and monitoring of regional-scale sea ice distribution, thickness and dynamics, there is strong reliance on satellite remote sensing (Lubin and Massom, 2006). In addition, the Antarctic Sea Ice Processes and Climate (ASPeCt) programme (http://aspect.antarctica.gov.au/home/conducting-sea-ice-observations) has been acquiring standardised routine observations from ships since the 1990s of ice concentration, ice and snow thickness, floe size and ice type. Information on other important properties of sea ice and its snowcover, including crystal structure (e.g., columnar versus frazil ice) require in situ observations.

A number of key improvements are required to the observing system for sea ice. Primarily, there is a need to calibrate and validate satellite retrievals of sea-ice thickness and snow thickness, to reduce current large uncertainty. Icebreakers need to be instrumented with autonomous sensor systems to routinely acquire standardised long-term measurements of fundamental sea-ice properties and habitat, including floe-size distribution, ice and snow thickness, ice type and deformation, wave-ice interaction and precipitation rate amongst other key parameters. The integration of observations using different autonomous technologies has a crucially important role to play, including air-borne platforms (UAVs) and under-ice platforms (ROVs, AUVs). The physical attributes and evolution of the sea ice-snow-atmosphere-ocean interaction system in time and space can be measured by autonomous ice mass balance buoys, but few have been deployed to date. Few observations have been made of the joint biological-physical properties of sea ice (Meiners et al., 2012), although there are good long-term records for fast ice off Syowa (Hoshai et al., 1980; Watanabe et al., 1990). Techniques and suitable algorithms are becoming available for improving biological measurements in sea ice (Meiners et al., 2017; Melbourne-Thomas et al., 2015). Improved mathematical modelling informed by improved observations and process understanding is critical (Hobbs et al., 2016) - to both better understand what is driving observed patterns of change and variability in the coupled sea ice-ocean-atmosphere-biology system across the Indian Ocean sector, and to improve prediction of its likely future trajectory in a changing climate over coming decades.

Biogeochemistry

Tom Trull: Southern Ocean Observing System - Key Drivers for biogeochemistry - planetary metabolism

4.10. Key drivers for biogeochemical observations are related to the dominant role of the Southern Ocean in responding to anthropogenic climate forcing:

i. 93% of the excess trapped heat has gone into the ocean, 75% of this by the Southern Ocean.

ii. 30% of anthropogenic CO2 emissions have been absorbed by the ocean, 40% of this by the Southern Ocean.

iii. 2% drop in ocean oxygen levels in the past century as a result of slowing circulation, with ~50% of this change supplied from the Southern Ocean

4.11. A decrease in global primary production is expected, though the magnitude of change is uncertain, (~ 1 to a few percent). It is likely to be modulated by Southern Ocean nutrient supply which contributes ~75% of nutrient supply to the global surface ocean. Assessing and tracking the ability of the Southern Ocean to continue to provide these ecosystem services is a key motivator of sustained observations. Circulation is the dominant control on heat, CO2 and O2 uptake and supply to the ocean interior; conversely biogeochemical measurements are useful tracers of circulation change. The biological pump modulates CO2 uptake, and is impacted by warming, melting, circulation changes, acidification, and iron availability (as the primary control on production); biogeochemical measurements contribute to the quantification of ecological changes.

4.12. These drivers and services are circumpolar but special properties of the Indian sector include:

i. Supply role for deep waters to Indian Ocean – host to the globally most intense oxygen minimum zone.

ii. Receiving role for waters of intensifying East Australian Current – which drives very rapid warming of SAZ in this sector, and brings new organisms (e.g. first observations of Noctiluca scintilans)

iii. Significant iron inputs from Kerguelen intraplate volcanoes/plateau – a different setting from the Scotia/ Sandwich Arcs in Atlantic

iv. Has regions where ACC particularly closely approaches Antarctic shelf and where AABW production slowdown is large (Adelie Land). - possibly endmembers in the panoply of system responses.

4.13. CO2 observations are the most advanced, compared to oxygen, nutrients, iron. Similar efforts are needed for other biogeochemical variables. pCO2 of surface waters is achieved with ships. It is relatively easy to measure, but highly variably in space and time. Analysis of these and other data have shown that the Southern Ocean CO2 uptake varies strongly on decadal timescales, in response to circulation changes. More effort is needed especially in the western portion of the Indian Sector. Moored observations are needed to resolve seasonal cycles. Currently there is only 1 platform (SOTS) in the SAZ.

4.14. DIC, alkalinity, and oxygen measurements are more difficult to measure than those above but are better for determining ocean changes over time, because they see the impact of the surface variability without its noise, and model frameworks can distinguish natural from anthropogenic CO_2. Measurements to the south of Tasmania show that the shallow ongoing uptake of fossil fuel CO_2 predominantly in the SAZ, has been accompanied by deep increases in DIC at depth, apparently as a result of circulation changes (driven by intensification of the westerly winds) that bring in more old deep waters from outside the Southern Ocean that are naturally enriched CO_2 levels from the biological pump. Some of this natural CO_2 degasses near the Southern ACC front, reducing the overall sink. Both sources of CO_2 decrease pH. Continuing the SR3 section repeats and bolstering the effort with other GO-SHIP sections is important.

4.15. Moving beyond surface and meridional overturning circulation views is essential to track the fate of CO_2 and associated acidification, oxygen ventilation, and nutrient supplies to fuel production outside the Southern Ocean. A region of importance is in the subantarctic zone to the southwest of Australia. Biogeochemical-Argo is the best tool for this, using the suite of CO_2, pH, nitrate sensors, augmented by bio-optics (Chl a-fluo, Bbp, radiometry) to deliver primary and export production estimates. The international implementation plan is on-line; the US SOCCOM, French SOCLIM and Aus-India biogeochemical and bio-optical float deployment pilot projects have been successful. It is hoped that the international implementation plan will advance the transition to operational observations.

4.16. While CO_2, oxygen and nutrients are being observed, there is an urgent need for a silica sensor. Iron remains more difficult to measure for three reasons:

i) The trace levels require highly specialised and costly teams, who can still only achieve low throughputs. There are no sensors.

ii) Not all iron is alike – the bio-availability of aerosol, sedimentary, and volcanic inputs remains variable and hard to quantify (abiotic Fe removal processes are similarly complex).

iii) Boyd and Ellwood (2010) identified 10 mechanisms of iron supply to the Southern Ocean, including several that are expected to increase with climate change, such as melting ice, wind driven aerosols, and boundary current supply from the north.

4.17. GEOTRACES hydrographic sections are essential, as is expanded effort to determine responses using remote sensing of phytoplankton properties (such as their photosynthetic competency)

Biology

Kerrie Swadling & So Kawaguchi: Zooplankton and krill in the Indian sector

4.18. From the SCAR Horizon Scan paper, we nominate the following questions from 'Antarctic Life on the Precipice' that could be addressed by the members of SOIS working on lower trophic levels: (1) Which ecosystems and food webs are most vulnerable in the Antarctic and Southern Ocean, and which organisms are most likely to go extinct? (2) How will invasive species and range shifts of indigenous species change Antarctic and Southern Ocean ecosystems? (3) What are the impacts of changing seasonality and transitional events on Antarctic and Southern Ocean marine ecology, biogeochemistry and energy flow? (4) How will deep sea ecosystems respond to modifications of deep-water formation, and how will deep sea species interact with shallow water ecosystems as the environment changes? (5) What will key marine species tell us about trophic interactions and their oceanographic drivers such as future shifts in frontal dynamics and stratification?

4.19. Information on key drivers of zooplankton and krill are being collected routinely by several nations and include the following: temperature, phytoplankton (standing stock and productivity), mixed-layer depth, salinity, pH, dissolved oxygen, depth. We also have time-series information from satellites, including chlorophyll a, and sea-ice extent and duration, although few joint physical-biological measurements have been acquired within the sea ice itself (Meiners et al., 2017). Finally, in some cases we have information about key predators, such as fish and birds and marine mammals. The Continuous Plankton Recorder (CPR) dataset from the Indian sector provides the best opportunity, at present, to assess changes in zooplankton distribution and abundance in light of environmental change. Preliminary analyses linking climate modes to zooplankton communities suggest that the Southern Annular Mode might be an important driver. Along with the CPR data, there some important data sets from early cruises, such as FIBEX, ADBEX, SIBEX, etc.; these datasets are based on tows of a rectangular mid-water trawl (RMT) net and could provide significant information on krill and other macro-zooplankton.

4.20. The krill box survey recently implemented by Australia, enables one to two week-long krill surveys on a regular basis. These surveys will be critically important to aid understanding of the dynamics of krill in the coastal Indian Ocean sector and the ecosystem, as well as predator-krill interactions, particularly in the vicinity of regularly monitored penguin colonies. At present, the number of research studies on Antarctic krill, Euphausia superba, exceeds that of other euphausiid species and most species of zooplankton, highlighting a key knowledge gap regarding the flow of energy via alternative trophic pathways (e.g., via salps or copepods-fish). This gap requires the design of process studies that can assess trophic pathways using stable isotopes, fatty acid analysis, grazing experiments, DNA and gut content analysis.

4.21. One important focus of such process studies should include the interaction between krill and salps, focussing on their role in the food web and flow of energy to higher trophic levels. There are regions in the Indian sector where krill and salps overlap in distribution and it is important to know the extent to which they compete for food and other resources. Key questions concerning krill and salp interactions include: (1) Is the area of occurrence of salps in the Indian sector also the area of production or is the southern distribution a consequence of passive transport within warmer water masses? (2) What are the effects of colder temperature on ecophysiology and reproduction of salps? i.e, how successful and durable is this south-ward shift in distribution? (3) What factors inhibit/support the co-occurrence of salps and krill? (4) How would the intrusion of salps in more southern areas change ecosystem dynamics (food web structure and fluxes of organic material)?

4.22. Other data gaps for lower trophic levels include knowledge of waters below 200 m, the ice-water interface and size spectra distribution for different regions (e.g. sea ice, coastal, deep ocean). Recent meta-analysis by Xavier et al. (2016) emphasises that sampling intensity in the pelagic zone is largely restricted to less than 200 m, yet we know that diversity of zooplankton increases with water depth. While sampling deep waters might not be a prime focus of SOIS, some targeted studies into these regions would be useful. At the surface, the ice-water interface is a difficult zone to sample quantitatively. The recent development of nets that can be attached to ROVs and AUVs (e.g., The MicroNESS; Guglielmo et al. 2015) could provide a routine method for sampling directly below the sea ice. Finally, automated instruments, such as the laser optical plankton counters and video plankton recorders, could revolutionise the ways in which we sample lower trophic levels by providing high throughput and minimising the long hours spent doing microscopy.

Kunio Takahashi – JARE zooplankton monitoring program & SO-CPR survey

4.23. The Japanese Antarctic Research Expedition (JARE) has been conducting routine zooplankton monitoring in the Indian sector of the Southern Ocean every austral summer (December–March) since 1972 (JARE-14). Zooplankton samplings were also carried out from TV Umitaka-maru during the 2013/2014 season (JARE-55) as a part of the JARE monitoring program. Two tools are used for zooplankton sampling; a NORPAC (NORth PACific) standard net and a CPR. The vertical hauls by NORPAC net were routinely and frequently carried out in order to estimate the mean biomass of surface zooplankton and its time-spatial variability in the upper layer. JARE NORPAC program is the only current long-term time-series zooplankton study in the Antarctica, which has been carried on for more than 40 years.

4.24. The Southern Ocean CPR (SO-CPR) Survey commenced in 1991 with the purpose of mapping spatial and temporal variations in zooplankton pattern, and to make use of the sensitivity of plankton to environmental change as an early warning indicator of the health of the Southern Ocean ecosystem. SCAR SO-CPR Database Group focused on maintaining the quality control and assurance of data entered into the SCAR SO-CPR Database, which will be achieved primarily through conducting taxonomic and methodological standardisation and training workshops. To date we have surveyed about 70% of the Southern Ocean but clearly there are distinct gaps where sampling is poor or non-existent because of the lack of shipping activity. We are at various stages in bringing in and assisting other nations, and are planning a training workshop for India to help them establish their SO-CPR work.

Ryosuke Makabe: Ecosystem dynamics and material cycling during sea ice melting season

4.25. Sea-ice melting is a significant event affecting ice edge blooms and material cycling in the Antarctic seasonal sea-ice zone, yet the related ecosystem processes are still unknown quantitatively. We developed a special drifter with modified GPS buoy frame, which can be protected against sea ice. The drifter array can be attached with sensor frames at multiple depths and also time-series sediment traps. The drifter will be deployed into the sea-ice zone (>50% in ice concentration) by the RV Shirase in early December, 2017, after then, retrieved by Umitaka maru in January, 2018. The study will reveal key ecosystem processes especially on fate of sea-ice biota, and contribute to SOOS themes 4&6.

Mark Hindell: Key Biology Drivers in the Southern Indian Ocean: Birds and Marine Mammals

4.26. Climate is the principal driver of bird and marine mammal populations in the Southern Indian Ocean. Its influence on animal populations is diverse in both its nature and in sensitivity, but in general, acts to influence the distribution and abundance of prey, or influence accessibility to prey or breeding sites. Over the last decade there have been many studies relating bird and marine mammal population parameters to various climate-related aspects of their physical environment. The most common factors are sea-ice extent, concentration and duration, water temperature, the location of frontal systems and the broad-scale indices of the Southern Annular Mode (SAM) and the Southern Oscillation index (SOI). Relationships have been found between at least one of these factors and some aspect of bird and mammal demographic performance whenever they has been investigated. However, these types of studies require long-term data sets and therefore reliable studies are still lacking for many species in many locations.

4.27. The long-term studies that have been conducted have revealed a diversity of biological responses among birds and mammals. For example, Wandering albatross perform well when SAM is in a positive phase (Fay et al., 2017) and yet Humpback whales do not (Irvine et al., in prep.). Sea surface temperature adversely effects species such as Antarctic fur seals (Baird-Bower et al in prep) and King penguins (Le Bohec et al., 2008) but the magnitude of the effect can vary in complex ways depending on intra-specific factors (age and sex), or inter-specific factors such as life history traits. Further, sea ice can act as a physical barrier for some species, such as Adélie Penguins (Emmerson and Southwell, 2008) and southern elephant seals (Clausius et al., 2017; McMahon et al., 2017).

4.28. There are two pressing needs in order to better understand these complex relationships. The first is to go beyond simple correlative studies. For example, describing a negative relationship between elephant seal foraging and SAM, is only the first step in explaining the proximate mechanisms driving the relationship. Broad-scale indices in themselves provide little in the way of direct mechanisms. Indeed, in all studies climate is only a distant proxy to prey availability, and while an ultimate driver, there are often complex down-stream and temporal lags that need to be taken into account. These details are poorly understood in the Southern Indian Ocean.

4.29. The second need is to standardise the demographic performance metrics used in the analyses. In the southern Indian Ocean, these currently include mass gain, survival, recruitment and reproductive success. While there are undoubted species-specific parameters, a comprehensive synthesis of the effect of climate on birds and mammals would benefit from commonality of measurements. The CCAMLR Ecosystem Monitoring Program (CEMP) is an example of where such a standardised approach has been developed, and which has resulted in a number of invaluable datasets. Adopting a similar approach, and establishing a network of sites where representative species are monitored in a routine way would provide long-term and sustainable monitoring. This is needed to quantify the status and trends of these species, and to elucidate the underlying mechanisms that determine population trajectories (and therefore long-term persistence) on the birds and mammals in the region.

Alix Post: Benthic habitats and geomorphology

4.30. Geomorphic features form the basis for understanding areas of high conservation value on the Antarctic margin such as Vulnerable Marine Ecosystems (VMEs). CCAMLR has measures aimed at protecting VMEs from bottom fishing, with features such as seamounts, hydrothermal vents, cold water coral communities and sponge fields listed as VMEs (CCAMLR Conservation Measure 22-06, 2015). Locating these features accurately can only be achieved through better bathymetric mapping and interpretation throughout the Southern Indian Ocean. Current geomorphic maps of the region are based primarily on satellite bathymetry which, at the time, had a resolution of 2-minutes of latitude and longitude (≈ 1.85km at 40°S)(Post et al., 2014).

4.31. Two important questions for benthic habitats and geomorphology with relevance to managers in CCAMLR, are:

i. What is the diversity and distribution of habitats and ecosystems in the Southern Indian Ocean?

ii. How are the composition, species diversity and vulnerability of these ecosystems changing?

4.32. At present, the first question is best addressed by mapping the distribution and diversity of seafloor features, such as geomorphology. Seafloor features delineate distinct sedimentary and oceanographic environments that can be related to major habitat characteristics. These features can then be targeted for closer monitoring of the associated ecosystems to assess change over time.

4.33. Characteristics of the benthic environment that would be useful to measure include sea-floor type (hard versus soft substrate), ice-keel scouring, sediment deposition or erosion and current regimes. On the Antarctic shelf, geomorphic features have been shown to provide an effective guide to the broad-scale distribution of benthic communities (Barry et al., 2003; Beaman and Harris, 2005; Koubbi et al., 2010; Post et al., 2011; Post et al., 2010; Smith et al., 2015).

4.34. Bathymetry maps over the majority of the Southern Indian Ocean are generally at 500m resolution (Arndt et al., 2013), which is not sufficient resolution for mapping the full distribution of important habitat forming features such as seamounts, ridges, canyons and hydrothermal vents. Higher resolution bathymetry grids are available for the Prydz Bay and Heard Island regions (at 100 m resolution), and from a single dedicated multibeam survey around Heard and MacDonald Islands (IN2016_V01; 10 m resolution). Grids at a resolution of 10 to 20m are considered optimal for the interpretation of seafloor geomorphology (Graham et al., 2008).

Human activities

Martin Exel: Australian fishing industry

4.35. The toothfish fishing industry in the vicinity of the Kerguelen Plateau is interested in whether changes in oceanography will cause changes in the availability or catchability of fish. In the longer term, the consequences of changing oceanography on the ecosystem and productivity of fish stocks (toothfish, icefish) is an important question: can we predict oceanographic conditions over the Kerguelen Plateau in 20 or 50 years? What role might the Southern Annular Mode and El Nino have in influencing this region of the Southern Ocean?

4.36. The fishing industry also wishes to understand what indicators or datasets would be useful for fishing vessels to collect to help develop models and analyses on these questions. Currently, a number of fishing vessels in the region collect and provide a wide array of data to various agencies, ranging from extremely fine scale, through to broader oceanic scale. For example, data are gathered off three vessels that operate between Mauritius to the north, and Heard Island to the South, including:

i. Active acoustic data from calibrated echo-sounders, steaming to and from fishing grounds

ii. Port to port satellite vessel position monitoring data

iii. Catch and effort data on the fishing grounds plus biological data for target and main by-catch species

iv. Fish tag, release and recapture data for main target species and some bycatch species

v. Seabird abundance index counts, at species levels, including any wildlife interactions and mitigation measures used recorded by observers

vi. Marine mammal interactions and occurrences, as well as photo identification for whales

vii. Benthic camera footage of specific regions

viii. Daily temperature, conductivity, depth profiles from sensors deployed on fishing gear in commercial operations and during annual surveys in the Australian EEZ around Heard Island.

ix. Passive acoustic ‘signature recorders’ for whales

x. Sea surface temperature from vessel collected although not calibrated

Dana Bergstrom, John van den Hoff: Plastics and micro-plastics in the Southern Ocean

4.37. Plastics in the Southern Ocean is an emerging issue (Waller et al., 2017). A global synthesis of plastics in the oceans showed little coverage in the Southern Ocean by 2014 (Eriksen et al., 2014). More recent analyses have shown plastic debris in sediments in the Ross Sea (Munari et al., 2017), in neuston samples taken between Hobart and Antarctica (Isobe et al., 2017), and in fur seal scats collected historically at Macquarie Island (van den Hoff, AAD, personal communication). It is proposed that systematic, standardised repeated sampling be undertaken, including visual surveys, neuston nets, filtered water and sediment sampling from ships, and surveys of animal scats, post mortems of dead animals, beach-combing and sediments on shore.

Modelling

Rowan Trebilco: Modelling Southern Ocean ecosystems with examples from the Indian Sector

4.38. Because of the scale and complexity of Southern Ocean ecosystems, many questions regarding their status, trends, structure and function can only be addressed with modelling. As models must reflect reality to be useful, observations are integral to their development. However, observation requirements vary with model type, and with the step of the modelling process. For example, in developing end-to-end ("physics to humans") model representations, the observation requirements for boundary conditions of physical model components (TS profiles etc.) will be very different to those required in developing biological model components (expert knowledge and dietary data), which in turn will be different to those required for evaluation and fitting steps (time series biological data, co-located observations of multiple components). So, the response to the question "what observations are required for your models" will inevitably be "it depends".

4.39. Nevertheless, there are key gaps for observations that would benefit a wide range of model types if filled. These gaps also represent opportunities where the 'value' of observations can be maximised. Observations in the sea-ice zone (especially measures of under-ice production and ice characteristics) are one such gap. Other general (not location-specific) gaps include: co-located (and co-incident) sampling of multiple ecosystem components (e.g. net sampling, acoustics, profiles, predator observations); and system-level structural knowledge (i.e. measures of relative biomass of key taxa, links, and flux rates).

4.40. In addition to asking the questions "what observations are needed for models", the observation and modelling communities should work together to consider "what models are needed for observations". Developing integrated model "toolboxes" with feedbacks between models and observations (including observation models and quality measures) has great potential for both improving models and developing optimised and scalable observing systems. Such a toolbox is being developed as an ensemble of ecosystem models currently by the

Antarctic Climate Ecosystems CRC for the Kerguelen Plateau and Prydz Bay region as an example.

Discussion & Future Work

4.41. The workshop participants agreed that a peer-reviewed publication summarising the key drivers in the Indian sector will be useful.

4.42. A bibliography of key papers, syntheses and special issues would be useful to support the development of these publications. A compilation of key scientific references for the Indian Sector will help the community plan and develop further collaborative observations and science programs. One possibility is to create a joint bibliographic database using Zotero. In doing this, a set of keywords will be helpful for searching relevant references under the different topics. The database could be used to help monitor progress of the SOIS Regional Working Group in the future, in terms of multidisciplinarity, partnerships, coverage of areas and disciplines, and uptake and use of the measurements.

Task 2. Compile a bibliography of published syntheses and special issues.

Task 3. Develop a manuscript on key drivers in the Indian Sector of the Southern Ocean.

4.43. Participants noted that clear definitions of the drivers will be needed, and an initial summary of the main attributes of the drivers in each box would be valuable e.g., mean and range of, say, depth, temperature, current speed. These summary attributes can then be used to help design where different measurements will need to be taken with respect to each driver. Further, sections of driver values by latitude would be useful for examining meridional differences between columns of boxes.

Task 4. Clarify the definition of each driver in order that the measurements required can be easily derived from the definitions.

Task 5. Summarise attributes of drivers in each box.

Task 6. Develop meridional sections for each column of boxes of mean driver values by latitude.

4.44. In order to identify where and when SOOS coverage is adequate, knowledge of the locations of important physical, chemical and biological drivers is needed. This will also help identify which overarching science and end-user questions will be addressed, and by which and how many observations. Following the heatmap of Figure 3, workshop participants started the development of a table showing the drivers of interest for each box and how much sampling may have been done to date (Figure 4). As for the heatmap, this summary will need community consultation after the meeting. It was noted that the identification of a driver in this process did not necessarily indicate a priority for associated research questions but that the driver is of interest for establishing sustained observations.

Task 7. Experts from each participating nation to summarise the areas in which measurements of key drivers will be valuable and what attention to these drivers have been given to date, following the approach in Figure 4.

Figure 4. Draft compilation of key drivers in each box of the Southern Ocean Indian Sector. 0 = not yet considered relevant to that box; drivers are considered relevant to the other boxes. 1 = driver not yet studied (red). 10 = measurements on the driver taken opportunistically (yellow). 11 = measurements on the driver are being taken and well supported (green). BAMM = birds and marine mammals.

Zone	sea ice	Eddy Field	bottom water	mCDW	ice shelves	movement of fronts	Fe: volcanic vents	Fe:islands	Fe: ice	Fe:eddies	Fe: Whales	Carbon sequestration	carbon ice edge	macro-nutrients	Sea-ice Algae	Sea-ice heterotrophs	POOZ phytolankton	Spring (ice edge) bloom	Zooplankton: krill densities	zooplankon: CPR	zooplankton: nets	Calcifiers	microbial loop	micronecton (mid-trophic level fish & squid)	BAMM: reproduction	BAMM: abundance	BAMM: at-sea	Benthos	demersal fish	fisheries
I6	0	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	11	0	0	0	1	0	0	10	0	0	0
I8	0	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	11	0	0	0	1	0	0	10	0	0	0
I9	0	11	11	11	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	11	0	0	0	1	0	0	10	0	0	0
SR3	0	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	11	0	0	0	1	0	0	10	0	0	0
1.1	11	10	10	10	11	0	0	0	1	1	0	10	1	11	1	0	10	1	0	11	11	10	1	0	11	11	11	1	0	1
1.2	0	10	10	10	0	0	0	0	0	0	0	10	0	10	0	0	10	0	0	11	10	10	1	0	0	0	11	0	0	0
1.3s	0	11	10	10	0	11	1	1	0	1	0	10	0	10	0	0	10	11	0	11	10	10	1	11	0	0	11	1	10	11
1.3n	0	11	10	10	0	11	1	1	0	1	0	10	0	11	0	0	10	11	0	11	11	11	1	11	11	11	11	1	10	11
1.4	0	11	10	10	0	11	1	0	0	1	0	10	0	11	0	0	10	11	0	11	11	11	1	11	0	11	11	0	0	0
2.1	11	11	11	11	11	11	0	1	1	1	0	11	1	11	1	0	11	1	1	11	11	11	11	11	11	0	11	11	0	1
2.2	0	11	11	11	0	11	1	1	0	1	0	11	0	11	0	0	1	11	0	11	11	11	11	0	0	1	11	10	0	11
2.3	0	11	11	11	0	11	1	1	0	1	0	11	0	11	0	0	1	11	0	11	11	11	11	11	0	11	11	10	1	11
2.4	0	11	11	11	0	11	0	0	0	1	0	11	0	11	0	0	1	11	0	1	11	11	11	1	0	11	11	0	0	0
3.1	11	1	10	10	1	11	0	0	1	1	0	0	1	0	1	0	1	1	0	11	0	0	0	0	0	0	11	1	0	0
3.2	0	1	10	10	0	11	0	0	0	1	1	0	0	0	0	0	1	0	0	11	0	0	0	0	0	0	11	0	0	0
3.3	0	11	11	0	0	11	0	11	0	1	0	11	0	11	0	0	11	0	0	11	11	11	11	11	11	11	11	11	11	11
3.4	0	11	0	0	0	11	1	1	0	1	0	0	0	11	0	0	0	11	0	11	11	11	11	11	11	11	11	10	10	11
4.1	1	11	11	11	11	0	0	0	1	0	0	1	11	11	11	11	11	11	10	11	11	11	1	11	1	1	11	1	0	0
4.2	0	11	11	11	0	10	0	0	0	0	0	0	0	11	0	0	11	0	10	11	11	0	1	11	0	0	11	0	0	0
4.3	0	11	0	0	0	10	0	0	0	0	0	0	0	11	0	0	11	0	0	11	11	0	1	1	0	0	11	0	0	0
4.4	0	11	0	0	0	10	0	0	0	0	0	0	0	11	0	0	11	0	0	11	11	0	1	1	0	0	11	0	0	0
5.1	11	0	10	10	1	0	0	0	1	0	0	0	1	0	1	0	0	1	1	11	0	0	0	0	1	1	1	1	0	0
5.2	1	0	1	1	0	0	0	0	1	0	0	0	1	0	1	0	0	1	0	11	0	0	0	0	0	0	1	0	0	0
5.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	1	0	0	0
6.1	11	1	11	1	0	1	0	0	1	0	0	0	1	0	1	1	1	1	1	11	11	0	1	11	11	11	11	11	11	0
6.2	1	1	10	10	0	11	0	0	1	1	0	0	1	10	1	0	11	1	0	11	11	0	0	0	0	0	1	0	0	0
6.3	0	1	0	0	0	11	0	0	0	1	0	1	0	10	0	0	11	0	0	11	11	0	0	0	0	0	1	0	0	0
7.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	1	1	0	0
7.2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	11	0	0	0	0	1	1	1	0	0	0
7.3	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	11	0	0	0	0	0	0	1	0	0	0

5. Status of Multidisciplinary Observations

2nd International Indian Ocean Expedition (2015-20): developing links with SOOS

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5.1. IIOE-2 is specified to run to 2020, however discussions are underway through the IIOE-2 Steering Committee on the merits, feasibility and likely support of extending IIOE-2 out into the next decade. This adds temporal context to the collaborative discussions underway for the building of links with SOOS and IIOE-2 under the auspices of the SOOS-SOIS Regional Working Group, established in 2017.

5.2. Background detail and materials (including those referred to in this talk such as reports, communication products etc) are available through the IIOE-2 website www.iioe-2.incois.gov.in.

5.3. The IIOE-2 Science Plan articulates many of the scientific relevancies of the Southern Ocean per se in respect to understanding current and projected bio-physical and coupled climate phenomena of the Indian Ocean, described through the objectives specified in the six scientific themes of the IIOE-2.

Theme 1: Human impacts (How are human-induced ocean stressors impacting the biogeochemistry and ecology of the Indian Ocean? How, in turn, are these impacts affecting human populations?)

Theme 2: Boundary current dynamics, upwelling variability and ecosystem impacts (How are marine biogeochemical cycles, ecosystem processes and fisheries in the Indian Ocean influenced by boundary currents, eddies and upwelling? How does the interaction between local and remote forcing influence these currents and upwelling variability in the Indian Ocean? How have these processes and their influence on local weather and climate changed in the past and how will they change in the future?)

Theme 3: Monsoon variability and ecosystem response (What factors control present, past and future monsoon variability? How does this variability impact ocean physics, chemistry and biogeochemistry in the Indian Ocean? What are the effects on ecosystems, fisheries and human populations?)

Theme 4: Circulation, climate variability and change (How has the atmospheric and oceanic circulation of the Indian Ocean changed in the past and how will it change in the future? How do these changes relate to topography and connectivity with the Pacific, Atlantic and Southern oceans? What impact does this have on biological productivity and fisheries?)

Theme 5: Extreme events and their impacts on ecosystems and human populations (How do extreme events in the Indian Ocean impact coastal and open-ocean ecosystems? How will climate change impact the frequency and/or severity of extreme weather and oceanic events, such as tropical cyclones and tsunamis in the Indian Ocean? What are the threats of extreme weather events, volcanic eruptions, tsunamis, combined with sea level rise, to human populations in low-lying coastal zones and small island nations of the Indian Ocean region?)

Theme 6: Unique geological, physical, biogeochemical, and ecological features of the Indian Ocean (What processes control the present, past, and future carbon and oxygen dynamics of the Indian Ocean and how do they impact biogeochemical cycles and ecosystem dynamics? How do the physical characteristics of the southern Indian Ocean gyre system influence the biogeochemistry and ecology of the Indian Ocean? How do the complex tectonic and geologic processes, and topography of the Indian Ocean influence circulation, mixing and chemistry and therefore also biogeochemical and ecological processes?)

5.4. The transition between the Indian and Southern oceans is an area requiring much further research in this context, beginning with the respective IIOE-2 and SOOS communities assessing and deciding what that interfacial region constitutes in a spatial sense, whether it be defined as a fixed or variable region in time and space, along with the motivating scientific phenomena underlying that definition.

5.5. Clarification is then required to agree on the key scientific objectives that align with the IIOE-2 and SOOS scientific frameworks, and that also harmonise interests across both. This can underpin collaborative pursuits, which could be initiated by ensuring representatives engage across governance and operational structures. The IIOE-2 has an established Steering Committee (below) and a secretariat facility in the form of a Joint Project Office, with one Node at the UNESCO IOC Perth Program Office (IOC PPO) and another at the Indian National Centre for Ocean Information Services (INCOIS). The Steering Committee structure is shown below (as further described in the IIOE-2 Implementation Strategy). Its supporting entities include six Science Theme teams (each respectively aligning with the Science Plan's themes, above) and seven operationally oriented 'Working Group' teams, including for example 'Working Group 2' for Data and Information Management. Each of these 13 teams have chairs and respective supporting members, providing one of the ways that SOOS stakeholders may wish to engage through membership, for which interested persons can nominate.

<table>
<tr><td>Co-Chairs (IOGOOS, SCOR, UNESCO IOC)</td><td rowspan="4">Joint Project Office (JPO)

Leading personnel represented on Steering Committee as ex-officio</td></tr>
<tr><td>Strategic Executive Level
One representative (leader) per each of the six science themes from the SCOR SPDC IIOE-2 Science Plan
+
One representative (leader) per each of the seven operational divisions to be established as IIOE-2 Working Groups
+
One representative per each major IOC regional body/committee (e.g. IOC AFRICA, IOCINDIO, IOC WESTPAC)</td></tr>
<tr><td>Regional Coordination Level
One representative per each IIOE-2 'national committee'</td></tr>
<tr><td>Science Delivery Level
One representative (i.e. Principal Investigator) per each 'major' IIOE-2 scientific research initiative, including a representative of the Early Career Scientists Network from the Capacity Development Working Group</td></tr>
</table>

5.6. To date, 25 research initiatives have been endorsed by the IIOE-2 Steering Committee, with many making provision for collaboration and voyage berths available to external scientists (see www.iioe-2.incois.gov.in). Despite this growing suite of activities, the interfacial region between the Indian and Southern oceans remains one that requires further interest and attention to examine fluxes, long-term changes to key bio-physical processes and the interplay between these two oceanic regions on Earth cycles. This has relevancy to oceanic and coupled climatic phenomena, especially under decadal and inter-decadal scenarios relating to climatic forcing and responses.

5.7. The IIOE-2 is genuinely interested in working with the SOOS community. It would bemutually beneficial to make optimal use of respective operational resources and scientific capacities to address the current set of mutually related scientific objectives. It would bring attention to possible new questions having both contemporary and longer terms relevancies under climate change scenarios across the complementary biological and physical spheres. The potential to combine the respective capacities of the IIOE-2 and SOOS communities to support capacity development is also a driver in terms of one of the key legacies that the two programs can create, respectively and potentially collectively.

Censusing Antarctic Predators from Space

Mark Hindell (Convenor of CAPS Capability Working Group in SOOS)

5.8. The development of cost-effective monitoring approaches to assess changes in Southern Ocean ecosystems is central to Theme Six of SOOS. However, collecting regular, systematic data on the status and trends of many bird and marine mammal populations in the Antarctic is often very difficult if not impossible. The remote location of the animals (e.g. rarely visited sub-Antarctic Islands), and the inaccessible nature of the habitat (e.g. the pack-ice), makes logistics too challenging and expensive to conduct regular population surveys of some species (e.g., pack-ice seals), at a spatial scale sufficient for assessing their regional-scale abundance and distribution. Consequently, our understanding of the status and trends in animal populations and their relationship with key habitat characteristics represents a major knowledge gap. However, emerging technologies have the potential to fill this gap and in recognition of this, SOOS established the Censusing Animal Populations from Space (CAPS) capability working group.

5.9. CAPS has a number of objectives:

i. To coordinate research and development into the use of satellite remote sensing for population assessment in order to implement regular monitoring of seals and birds in the Southern Ocean using high resolution satellite images and

ii. undertaking a global census of Antarctic pack-ice seals

iii. To develop standardised survey methodologies;

iv. To develop methods for validation, and algorithms for transformation of images to estimates of abundance;

v. To deliver population estimates and other products to end users such as CCAMLR, SOOS, and SCAR.

5.10. The high-resolution images are obtained from latest generation satellites such as WorldView-3. This is the first multi-payload, super-spectral, high-resolution commercial satellite sensor operating at an altitude of 617 km. WorldView-3 satellite provides 31 cm panchromatic resolution, 1.24 m multispectral resolution, 3.7 m short wave infrared resolution and 30 m CAVIS resolution. The satellite has an average revisit time of <1 day and is capable of collecting up to 680,000 km2 per day. In terms of costs, 0.6m pan chromatic images (sufficient for counting seals) US$16.00 per km2. To put this in context, repeating the East Antarctic component of the ship-based APIS surveys on the 1990s using satellites would cost approximately US$400K, an order of magnitude less than the cost of multiple dedicated cruises.

5.11. Satellite images have now been used successfully to count whales, emperor penguins, Royal Albatross, elephant seals and Weddell seals. A major task for the members of CAPS is to develop automated, machine learning algorithms to enumerate animals in the images, as manual searching is time consuming and prone to human error. Several groups within CAPS are working on the problem.

5.12. In terms of the global pack-ice seal census, three nations are currently conducting regional surveys in order to develop the techniques and importantly ground-truth the algorithms. The UK is working in the WAP, the US in the Ross Sea and Australian in the Southern Indian Ocean. Contributions for other nations would be most welcome. The Australian program has been going for two years, and has learnt some valuable lessons. In 2015/16, only one of the 5 tasked images was delivered due to persistent cloud cover in the region that year. This reinforces an important point; image acquisition is highly weather dependent, and may result in data not being available every year. This may require a re-think about the temporal nature of surveys in the region. After year two, 9 out of 10 requested images were available, and this was enough to begin preliminary habitat models.

5.13. Ground-truthing and machine learning remain high priorities for the group and a number of student projects are being devoted to this question. However, the value of the approach in providing fundamental data on status and trend of poorly surveyed species is now well established, and high-resolution satellite images will become an important tool for SOIS.

Southern Ocean Time-Series (SOTS)

Tom Trull (Chief Investigator of SOTS for IMOS)

5.14. The Southern Ocean Time Series (SOTS) is a set of deep ocean moorings southwest of Tasmania (in SOIS Box 6.3), serviced once a year, measuring more than 150 parameters important to climate and carbon cycle processes (http://imos.org.au/facilities/deepwatermoorings/sots/). Recent results for the full seasonal pCO2 cycle with hourly resolution reveal that the biological carbon pump is as effective in these high-nutrient low-chlorophyll (HNLC) Subantarctic waters as in North Atlantic high-chlorophyll spring bloom waters. Current work is attempting to determine the role of community ecology in this effectiveness, using detailed information on four biogeochemical compartments (nutrients, phytoplankton, zooplankton, detritus) collected by the moorings, including plankton taxonomic composition from autonomously collected water samples. SOTS began in 1997 as a sediment trap program and has grown to become a multi-disciplinary effort that covers variables ranging from air-sea fluxes, to NPZD foodweb dynamics including acoustic imaging of fish and zooplankton diel migrations.

5.15. The SOTS comprises up to three moorings: the SAZ sediment trap mooring has a stiff subsurface design with paired traps and current meters at 1000m, 2000m, and 3800m. These traps are McLane Parflux funnels with fortnightly time series sample carousels, and in some years have been augmented with indented rotating-sphere zooplankton-excluding traps. The Pulse BGC Mooring has a 1 m diameter, 0.5m freeboard float; an elastic decoupler, inertial mass, S-tether, integrated instrument package; Aanderaa Optode O2; Seabird T, S, Electrode O2; Pro-Oceanus Gas Tension; Mclane RAS 24x2x500ml water samples: nutrients, DIC, Alk, Phyto ID; Wetlabs PAR, Fluo-Backscatter; and an ISUS UV nitrate sensor. In recent years the Pulse mooring has not been deployed and these instruments have been instead mounted on the third mooring type – the large s-tether SOFS meteorological tower mooring.

5.16. All data and links to the large set of SOTS publications are available via www.imos.org.au. Samples are available via collaboration agreements: please contact Tom.Trull@csiro.au. SOTS is currently expected to continue through at least 2022. SOTS is a member of the OceanSITES global array of time series stations (www.OceanSITES.org).

Essential Ocean Variables

Andrew Constable (SOOS Co-chair Biology)

5.17. SOOS is developing a set of Essential Ocean Variables (EOVs), following the guidelines of the Framework on Ocean Observing (FOO), which was established after the OceanObs meeting in 2009 (link here). Many EOVs have been described for the Global Ocean Observing System (link here). SOOS aims to use these as much as possible. A number of EOVs will need to be made specific to the Southern Ocean and yet others will be unique for the purposes of Southern Ocean scientists, including chemical and biological (ecosystem) EOVs. Given the difficulties in regularly observing much of the Southern Ocean, the system of EOVs and their implementation will need to be pragmatic and focus on the fundamental variables that underpin the Southern Ocean system and its changes. Over the next 2 years, SOOS will be reviewing its listed EOVs (e.g. biology - http://www.soos.aq/resources/publications?view=product&pid=38) and elaborating how they might be implemented by the regional working groups. In the process of designing the observing system, SOOS needs to determine what are the priorities for measurements (EOVs), where, when and how often they need to be measured, and how best they could be measured. Biology has the least developed set of EOVs. In this case, ecosystem Essential Ocean Variables will comprise measurements of habitats (environmental envelopes), relationships of biota to habitats, temporal dynamics of habitats & biota, ecological connectivity, and change in biological structure and function (Constable et al., 2016).

6. Observational gaps, regional priorities, and challenges

6.1. The workshop participants considered the main steps in developing the regional working group, in terms of gaps in the existing observing activities, what the regional priorities would be and what the major challenges might be in the immediate future. The participants noted that the immediate work program needed to collate and synthesise existing ideas and activities in the region under the following headings in order to progress the implementation of the SOOS in the Indian Sector (Figure 5):

i. The geography of the region, including depth strata (relating to Task 5 Task 6)

ii. Questions and drivers of the region (relating to Task 2 Task 4 and Task 5)

iii. Essential Ocean Variables

iv. Historical Measurements

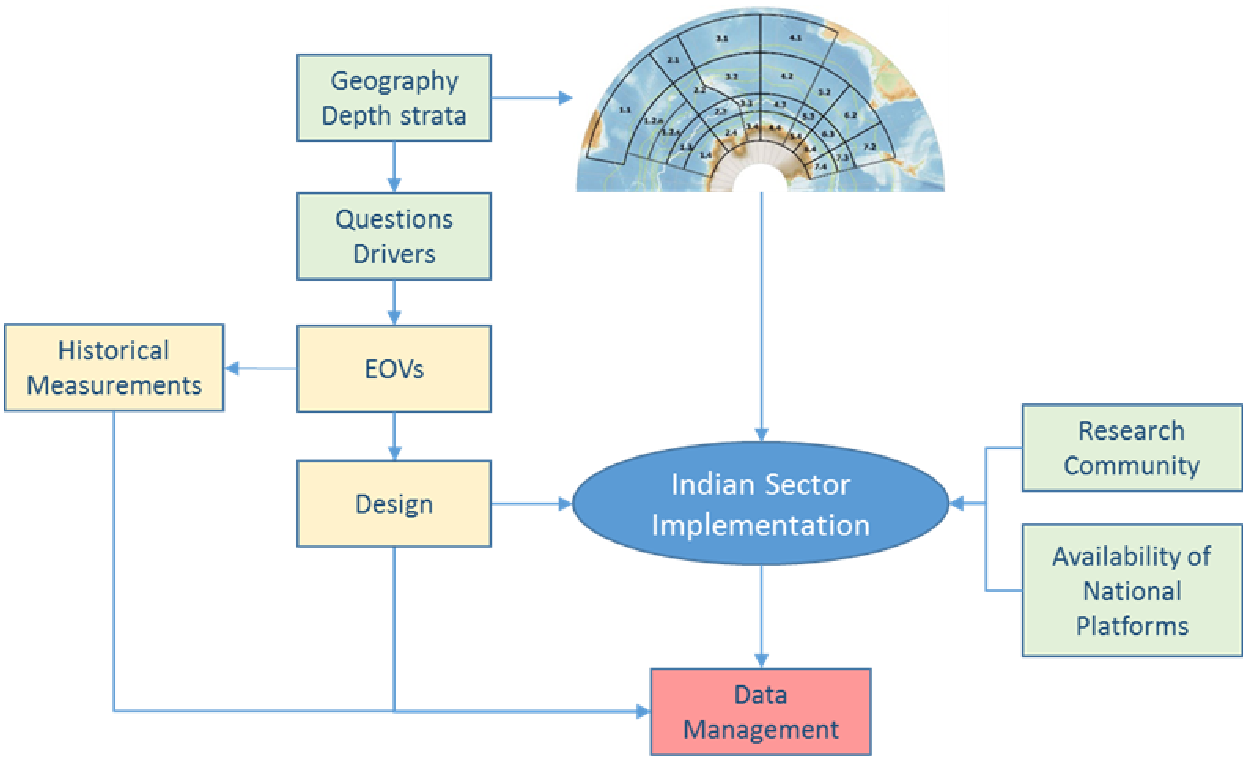
v. Design of the observing system

vi. Data management

vii. Research community

viii. Availability of national platforms

Figure 5. Schematic showing the links between areas for coordination and implementation of the observing system in the Southern Ocean Indian Sector. Background colours in a box are intended to indicate the degree of progress in each box: green = advanced, yellow = underway at workshop, red = yet to be considered.



EOVs for the Indian Sector

6.2. The workshop participants noted the need to participate in the development and adoption of SOOS EOVs, consistent with GOOS EOVs and other developments including, for example, the Australian Integrated Marine Observing System (http://imos.org.au/) and the USA Integrated Ocean Observing System (https://ioos.noaa.gov/). Participants reviewed the SOOS and GOOS EOVs and made comments on what comparable measurements may be priorities in the Indian Sector (Table 3).

Task 8. Circulate the list of candidate EOVs in Table 3 to the scientific community to review and rate:

- Usefulness: 1 = useful but of national, not universal importance; 2 = useful; 3 = essential
- Required regularity: 1 = needed yearly; 5 = every 5 years; 10 = 10 years; 100 = only once or updates only required very occasionally (e.g. bathymetry)
- Frequency within year: (seasonality; 52 = weekly; 365 = daily; 1 = only once yearly)

Task 9. Undertake a process for choosing a subset of EOVs for implementation in a first stage, and a second set for developing the documentation and progressing implementation in a second stage.

Historical Measurements

6.3. The workshop participants noted the task to collate summaries of measurements already undertaken, using a heatmap approach (Task 1). Once summarised, the following tasks will need to be undertaken:

Task 10. Identify data repositories where the data is available

Task 11. Encourage data owners/holders to correspond with SOOS IPO and Data Management Committee to curate metadata records - initially focussing on digital data. In the future it would be valuable to develop metadata records for data that has not yet been digitised; this will help identify what historical data needs to be curated and made available for specific purposes.

Task 12. Finalise summaries of data available based on metadata records

6.4. For an example of the value of such repositories, participants are encouraged to review the Australian Ocean Data Network (AODN) at IMOS (https://portal.aodn.org.au/)

Design

6.5. The design of the SOOS is being progressed in a task team, which needs inputs from each regional working group. These will include the use of simulation models to undertake Observing System Simulation Experiments (OSSEs). For the Indian Sector, it will be valuable for each nation to summarise their current activities and plans for the different areas of the Indian Sector. Figure 6 shows an example table for each nation to complete and submit on its existing plans, in order to determine existing coverage in the region. The next step would then be to review the locations of key drivers and the EOVs to be implemented in order to develop strategies for areas not covered by existing activities. Standard methods will be developed to assist this implementation.

Task 13. For each nation, summarise existing and planned measurements in the different areas of the Indian Sector according to Figure 6.

Task 14. Review standard methods for different measurements in SOKI (www.soki.aq) and add methods that may be needed.

Task 15. Develop implementation plan for the first set of EOVs, with an initial focus on main areas of activities at present, followed by areas in need of measurements.

Table 3. Lists of candidate essential ocean variables (EOVs) for the Southern Ocean Observing System, comparable variables in the Global Ocean Observing System and types of measurements considered at the workshop for the Southern Ocean Indian Sector (SOIS).

SOOS	GOOS	SOIS			
Bottom Topography		Bathymetry			
		Geomorphology			
Velocity	surface currents	Currents			
	subsurface currents				
Microstructure					
Tracers	transient tracers				
sea surface height	sea surface height	SSH			
Wind/accumulation	sea state	atmosphere?			
	ocean surface stress				
	ocean surface heat flux				
Seabed pressure					
Temperature	sea surface temperature	CTD-ship	CTD-seals	CTD-floats	CT U-way
	subsurface temperature	CTD-ship	CTD-seals	CTD-floats	
Salinity	sea surface salinity	CTD-ship	CTD-seals	CTD-floats	CT U-way
	subsurface salinity	CTD-ship	CTD-seals	CTD-floats	
Oxygen	oxygen	DO		CTD-floats	
Nutrients	nutrients	Nutrients	Nutrients U-way		
Ice shelves					
Ice shelf topography					
ice shelf thickness					
ice shelf flow speed					
glacier topography					
glacier flow speed					
ice shelf basal melt/freeze rates					
ice shelf englacial temperatures					
sea ice cover/concentration	sea ice	Sea ice conc			
sea ice thickness		Sea ice thick			
sea ice drift					
sea ice types		x			
		Polynyas			
carbonate system		pCO2			
		pH			
suspended particulates	suspended particulates				
	inorganic carbon				
particulate matter export					
nitrous oxide	nitrous oxide				
carbon isotope 13C	stable carbon isotopes				
dissolved organic matter	dissolved organic carbon				
hyperspectral reflectance					
multispectral backscatter	ocean colour				
photosynthetically active radiation					
fluorescence					
multispectral irradiance					
		Trace elements			
benthic species (diversity, abundance)		Benthos			
		Fish demersal			
protists-zooplankton-mesopelagic fish (biomass-rel abund-size spectrum)	phytoplankton biomass and diversity	Phytoplankton	Phyto U-way		
		Chlorophyll			
		Pigments			
		Microbes			
	zooplankton biomass and diversity	Zoo plankton	Zoo U-way (CPR)	Zoo U-way (water)	
		Size spectrum			
		Acoustics			
	fish abundance and distribution	Fish pelagic			
		Fish larvae			
		Acoustics			
		Size spectrum			
krill (density-size spectrum)		Density			
		Acoustics			
		Size spectrum			
marine mammals and birds (abundance, foraging range, diet, reproductive success)	marine turtles-birds-mammals abundance and distribution	BAMM abundance			
		BAMM breeding			
		BAMM tracking			
	live coral				
	seagrass cover				
	macroalgal canopy	macroalgal canopy			
	mangrove cover				

Figure 6. Summary heatmap to be used by nations for summarising their existing and future activities in the Indian Sector. Zones are the GO-SHIP sections and the areas within the Southern Ocean Indian Sector. The groups of columns are different types of platforms that may be used for the measurements. Individual columns represent the seasons of the year: SP = spring, SU = summer, AU = autumn/fall, WI = winter. The last column in a group, Yrs, is to indicate the number of years for which measurements are planned. The number for a zone within a season is to represent the number of measurements to be taken.

	Section/transect (ship, line of moorings, gliders, AUVs)					Area pattern (area survey, moored array)					Haphazard (animal tracks, floats, SOOP)					Point station (moorings, colony surveys)				
Zone	**SP**	**SU**	**AU**	**WI**	**Yrs**	**SP**	**SU**	**AU**	**WI**	**Yrs**	**SP**	**SU**	**AU**	**WI**	**Yrs**	**SP**	**SU**	**AU**	**WI**	**Yrs**
I6																				
I8																				
I9																				
SR3																				
1.1		1			5		1			1						1				5
1.2		1			5															
1.3n																				
1.3s																				
1.4																				
2.1		1			5															
2.2		1			5															
2.3																				
2.4																				
3.1		1			5															
3.2		1			5															
3.3																				
3.4																				
4.1		2	1		5		1			2		1			2	1	1	1	1	2
4.2		2			5		1			2										
4.3		2			5															
4.4		2			5															
5.1			1		5															
5.2		1			5															
5.3																				
6.1			1		5															
6.2			1		5															
6.3		1	1		5															
7.1																				
7.2																				
7.3																				

National Platforms and Programs

6.6. Workshop participants agreed to summarise national platforms and programs after the workshop.

Task 16. Experts from each Indian Sector nation contribute relevant summaries of the following attributes of their national programs:

- *Key organisations, agencies and contacts including funding bodies*
- *Active areas and observational platforms*
  - *summarise geographic areas of activities and the platforms used in each area.*
  - *if regular locations (areas), stations, transects, sections are undertaken then it would be useful to document these and have GIS shape files developed for input to SOOS Due South*
- *Summary timeline of activities*
- *Key plans and publications*
- *Key Data Repositories*

Research Community

6.7. Workshop participants considered the development of task teams within the working group. The teams suggested are:

i. Oceanography

ii. Ice

iii. Atmosphere

iv. Biogeochemistry

v. Benthic environment

vi. Primary and secondary producers

vii. Fish & squid

viii. Marine mammals and birds

ix. Modelling and Observing System Design

Lists of people to be approached to participate in the teams were also compiled. Each team will be open to participation by anybody interested.

Task 17. Identify key contacts (physics, chemistry, biology) within each nation to help with coordination of national contributions to the regional working group.

Task 18. Write to each of the suggested task teams and ask if they would like to be involved, who else might be involved in the Indian Sector work, and who would they, as a group, like to have as a contact point (lead the task team).

7. Key Objectives for the SOIS RWG

7.1. The workshop participants reviewed the draft 'terms of reference' for the SOIS Regional Working Group provided by the SOOS Scientific Steering Committee (Attachment C). They agreed that it would be better to title these as "Key Objectives" as this would be more engaging.

7.2. In terms of participation, it was agreed that a number of co-chairs is desirable with at least one representative from each nation operating in the region. It would be highly desirable to have a mix of physicists, chemists and biologists from each nation, preferably representing the different fields of oceanography, ice, biogeochemistry, lower trophic levels, higher trophic levels, atmosphere, and benthic environment. The group will aim for a balance of gender and experience in responsible roles and encourage early career researchers to be involved. The participants agreed that observers from relevant organisations would be encouraged, including from the 2nd International Indian Ocean Experiment, fishing industry and others.

8. Next Steps

8.1. Workshop participants considered some general tasks for consideration in the future, including:

• Group structure, communication, development

• Data management, repositories and products

• Funding and Linkages

• Linkages to international research and observation bodies

- SCAR, WMO, ICED, MESOPP, CCAMLR, IIOE-2

• Options for obtaining support from national programs

• Outputs

- Development of two papers on the Indian Sector (below)

- Using DueSouth and SOOSmaps to document field programs

Task 19. Two papers to be prepared for the peer-reviewed literature from the regional working group would be useful in the short term:

i. Measuring change in the Indian Sector of the Southern Ocean - contributions to the Southern Ocean Observing System

ii. Review of biology interaction with climate impacts in the Indian Sector

8.2. The tasks identified through the report are summarised in Attachment D. Workshop participants noted that the development of the tasks would be a high priority and that, if possible, meeting again in the next 18 months would be valuable.

Attachment A: Agenda and Program

Saturday 12 August 2017	
Arrive during the day	
Informal get together in late afternoon	
Sunday 13 August 2017	
0900 - 1030	
Opening & Introductions	Tsuneo Odate
Local organisation	Tsuneo Odate Mosato Moteki
SOOS Regional Working Groups and structure of meeting	Andrew Constable
1100 - 1240	
Current marine science activities in the Indian Sector	Philippe Koubbi
Japan	Tsuneo Odate (10min) Mosato Moteki (10min)
Australia	Andrew Constable (10min) Clive McMahon (10min)
France	Philippe Koubbi (20min)
China	Jiuxin Shi (10min) Guoping Zhu (10min)
India	N. Anilkumar (10min) R.K. Mishr (10min)
1400 - 1600	
Breakout groups to discuss and document national programs in the region	
1600 - 1730	
Report back and discuss what further work will be needed to document national activities	
Monday 14 August 2017	
0900 - 1030	
3. Key drivers in the region (relating to SOOS themes)	Tsuneo Odate
Ocean-atmosphere	Kohei Mizobata (10min) Keishi Shimada (10min)
Cryosphere	Klaus Meiners, Rob Massom (proxy-10min) Takeshi Tamura (10min)
Biogeochemistry	Tom Trull (proxy)
Biology	Kerrie Swadling (10min) Kunio Takahashi (10min) Ryosuke Makabe (10min) Mark Hindell (10min)
Modelling	Rowan Trebilco (10min)
General Discussion	
1100 - 1230	
4. Status of multidisciplinary observations	Andrew Constable

Indian Ocean Experiment 2	Nick d'Adamo (20min)
Southern Ocean Time Series	Tom Trull (proxy-10min)
Censusing Antarctic Predators from Space	Mark Hindell (20min)
EOVs	Andrew Constable (20min)
1400 - 1530	
Breakout groups to discuss and document platforms available in the Indian Sector - including potential for innovation	
1600 - 1730	
Breakout groups to discuss and document plans for national activities (1-3 years, 5 years, 10 years), including strategic plans and data management and repositories	
Tuesday 15 August 2017	
0900 - 1030	
5. Key observational gaps, regional priorities, and challenges	Philippe Koubbi
Report back from breakout groups	
Discuss development of EOVs for the region	
1100 - 1230	
Discuss gaps, priorities and challenges	
1400 - 1530	
Discuss feasible program of work and milestones	
1600 - 1730	
6. Terms of References for the SOIS RWG (Perhaps change Terms of Reference to say "Key Objectives" - more engaging.)	Andrew Constable
Consider and revise as needed the terms of reference for the group.	
Wednesday 16 August 2017	
0900 - 1030	
7. Where to from here	
Possible meetings for further discussion	Philippe Koubbi
2nd Kerguelen Plateay Symposium, November 2017	
Marine Ecosystem Assessment of the Southern Ocean (MEASO), April 2018	
SOOS Science Steering Committee Meeting, May 2018	
SCAR Open Science Conference, June 2018	
Group structure, communications, development	
Data management, repositories and products	
Funding and linkages	Andrew Constable
Linkages to international research and observation bodies e.g. SCAR, WMO, ICED, MESOPP, CCAMLR, IOOE-2	
Options for obtaining support from national programs	
1100 - 1230	
Consider outputs	Andrew Constable
Publication	
Using DueSouth and SOOSmap to document field programs	
Report	
EOVs and workplan	
1230 - Meeting close	Tsuneo Odate

Attachment B: General Acronyms

AAD	Australian Antarctic Division
AADC	AAD Data Centre
AABW	Antarctic Bottom Water
ACC	Antarctic Circumpolar Current
ADCP	Acoustic Doppler Current Profiler
AIS	Amery Ice Shelf
AODN	Australian Ocean Data Network
ASPeCt	Antarctic Sea Ice Processes & Climate
AUV	Autonomous Underwater Vehicle
CAPS	Censusing Antarctic Predators from Space
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CHINARE	Chinese National Antarctic Research Expedition
CPR	continuous plankton recorder
CSIRO	Australian Commonwealth Scientific and Industrial Research Organisation
CTD	Conductivity, Temperature and Depth
EOV	Essential Ocean Variable
GEOTRACES	International Study of Marine Biogeochemical Cycles of Trace Elements
GO-SHIP	Global Ocean – Ship-based Hydrographic Investigations Program
GOOS	Global Ocean Observing System
IIOE-2	Second International Indian Ocean Experiment
ILTS	Institute of Low Temperature Science, Hokkaido University
IMAS	Institute for Marine and Antarctic Studies, University of Tasmania
IMOS	Integrated Marine Observing System, Australia
IPEV	French Polar Institute
JARE	Japanese Antarctic Research Expeditions
NCPOR	National Centre for Polar and Ocean Research, India
NIPR	National Institute for Polar Research, Japan
OSSE	Observing System Simulation Experiment
POOZ	Permanent Open Oceanic Zone
ROV	Remotely-operated vehicle (tethered, underwater)
ROBOTICA	Research of Ocean-ice BOundary InTeraction and Change around Antarctica
RWG	Regional Working Group
SACCf	Southern ACC Front
SAM	Southern Annular Mode
SAZ	SubAntarctic Zone
SIZ	Seasonal sea ice zone
SOCCOM	Southern Ocean Carbon and Climate Observations and Modelling program, USA
SOCLIM	Southern Ocean Climate field program, France
SOIS	Southern Ocean Indian Sector
SOOS	Southern Ocean Observing System
SOCRATES	Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study
SOTS	Southern Ocean Time Series
TUMSAT	Tokyo University of Marine Science and Technology
UAV	Unoccupied aerial vehicle
VME	Vulnerable Marine Ecosystem
WOCE	World Ocean Circulation Experiment
XBT	Expendable BathyThermograph

Attachment C: SOOS Southern Ocean Indian Sector (SOIS) Regional Working Group

SOOS Request for Assistance.

The Southern Ocean Observing System (SOOS) is an international initiative that aims to facilitate the collection and delivery of essential observations on variability and change of the Southern Ocean systems to all international stakeholders through the design, advocacy, and implementation of cost-effective observing and data delivery systems. SOOS requests assistance in developing the community, best practices, and initiatives through community Working Groups (WG). These WGs will provide critical information that will be incorporated into a maturing SOOS. SOOS will provide the WG with (i) a means of incorporating grass roots ideas into a lasting international system, (ii) mechanisms for enhancing collaboration and resources, and (iii) a means for achieving citations of developed products along with a presence on the world-wide web.

SOOS Working Group SOIS Mission

To assist delivery of coordinated and, where possible, standardised observations of essential physical, chemical and biological variables in the Southern Ocean's Indian Sector (SOIS) in support of the Southern Ocean Observing System.

Key Objectives

The working group (WG) will fulfill the following key objectives over the next 5 years:

1. Develop and enable regional-scale observing encompassing the six themes of SOOS in the SOIS using SOOS best practice for the observing system.
2. Identify and assemble legacy data sets and sampling techniques of ships and stations in the SOIS in order to provide best practice sampling protocols for parameters1 to enable their standardisation, which may include adoption of standards from other international programs. Sampling approaches and recommendations will be made available on the SOOS Web site.
3. Based on the experience in the SOIS, identify gaps and bottlenecks in the observation systems and contribute to SOOS in addressing these issues. Facilitate co-ordinated observations between different nations in the region and, where possible, facilitate coordinated multi-disciplinary (physical, chemical and biological) observations. Plans, operations and meta-data will be made available on the SOOS web site to help collaboration amongst the international community.
4. Facilitate and, when needed, develop procedures to achieve efficient sharing of data across the science community according to SOOS data policy.
5. Convene focussed sessions at national and international meetings, including SCAR and SCOR, and facilitate synthesis products, to increase the awareness of the science community to the importance of the SOIS.
6. Provide support to International Program Office (IPO) by providing annual reports to be

available at the SOOS SSC annual meeting, as well as providing content for the IPO website/newsletters on the activities and outcomes of the Indian Sector Working Group.

7. Develop a funding plan to sustain the Working Group activities.
8. Have products coming out of the WG acknowledge SOOS
9. Contribute to and liaise, as practical, with international initiatives relevant to assessing the state of the SO and its interrelationships with neighbouring oceans and the globe more generally

Participants

A minimum 2 co-chairs from different countries is required; however large WGs are encouraged to have an executive committee or structure that can share the administrative burden and help the group to work efficiently. Ideally, there would be representation from each country with research activities in the SOIS within all relevant[1] disciplines. These representatives would be requested to coordinate input into the WG activities from participating nations and help facilitate coordinated, standardized observations in the future. Participants would help organize workshops and meetings to facilitate the work of the WG. If approved, a call will be made for expressions of interest by scientists, particularly from these countries who are knowledgeable about observations in the sector, to participate in the working group.

Products and Outcomes

· Table of existing sampling practices of ships and stations in the region posted on SOOS Web site, along with planned activities.
· Identification of gaps in observations and possible means of coordinating between nations to deliver a comprehensive suite of observations from the region.
· Agreement for data sharing among the science community and provision of data streams to SOOS.
· Publications in a peer-reviewed journal on latest evidence for dynamics and change in the region and future research priorities.
· Deliver innovative products identified as SOOS contributions, which can be used by researchers to solve science and management problems.
· Documentation and guidelines to facilitate national operators following the best practice for collection of data on priority variables.

Mode of Operation

The group will work remotely and opportunistically at scientific conferences until funding can be arranged for the group's activities. The SOKI wiki is proposed to be used to facilitate the delivery of the terms of reference.

Strategy & Milestones

The first task of the Working Group will be to develop a strategy for the next 5 years to deliver the products and outcomes identified above along with an implementation strategy for the region.

Co-Chairs

Andrew Constable[1,2,5], Tsuneo Odate[3,6], Philippe Koubbi[4,7]

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[1] Physics, chemistry, biology, and/or sea ice

Attachment D: List of tasks identified by the Regional Working Group

Task 1. *Experts from each participating nation to summarise measurements taken by their nation in the Indian Sector using the heatmap approach in Figure 3.*

Task 2. *Compile a bibliography of published syntheses and special issues.*

Task 3. *Develop a manuscript on key drivers in the Indian Sector of the Southern Ocean.*

Task 4. *Clarify the definition of each driver in order that the measurements required can be easily derived from the definitions.*

Task 5. *Summarise attributes of drivers in each box.*

Task 6. *Develop meridional sections for each column of boxes of mean driver values by latitude.*

Task 7. *Experts from each participating nation to summarise the areas in which measurements of key drivers will be valuable and what attention to these drivers have been given to date, following the approach in Figure 4.*

Task 8. *Circulate the list of candidate EOVs in Table 3 to the scientific community to review and rate:*

- *Usefulness: 1 = useful but of national,not universal importance; 2 = useful; 3 = essential*
- *Required regularity: 1 = needed yearly; 5 = every 5 years; 10 = 10 years; 100 = only once or updates only required very occasionally (e.g. bathymetry)*
- *Frequency within year: (seasonality; 52 = weekly; 365 = daily; 1 = only once yearly)*

Task 9. *Undertake a process for choosing a subset of EOVs for implementation in a first stage, and a second set for developing the documentation and progressing implementation in a second stage.*

Task 10. *Identify data repositories where the data is available*

Task 11. *Encourage data owners/holders to correspond with SOOS IPO and Data Management Committee to curate metadata records - initially focussing on digital data. In the future it would be valuable to develop metadata records for data that has not yet been digitised; this will help identify what historical data needs to be curated and made available for specific purposes.*

Task 12. *Finalise summaries of data available based on metadata records*

Task 13. *For each nation, summarise existing and planned measurements in the different areas of the Indian Sector according to Figure 6.*

Task 14. *Review standard methods for different measurements in SOKI (www.soki.aq) and add methods that may be needed.*

Task 15. *Develop implementation plan for the first set of EOVs, with an initial focus on main areas of activities at present, followed by areas in need of measurements.*

Task 16. Experts from each Indian Sector nation contribute relevant summaries of the following attributes of their national programs:

- *Key organisations, agencies and contacts including funding bodies*
- *Active areas and observational platforms*
  - *summarise geographic areas of activities and the platforms used in each area.*
  - *if regular locations (areas), stations, transects, sections are undertaken then it would be useful to document these and have GIS shape files developed for input to SOOS Due South*
- *Summary timeline of activities*
- *Key plans and publications*
- *Key Data Repositories*

Task 17. Identify key contacts (physics, chemistry, biology) within each nation to help with coordination of national contributions to the regional working group.

Task 18. Write to each of the suggested task teams and ask if they would like to be involved, who else might be involved in the Indian Sector work, and who would they, as a group, like to have as a contact point (lead the task team).

Task 19. Two papers to be prepared for the peer-reviewed literature from the regional working group would be useful in the short term:

i. Measuring change in the Indian Sector of the Southern Ocean - contributions to the Southern Ocean Observing System

ii. Review of biology interaction with climate impacts in the Indian Sector

Attachment D: References cited in the report

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